NAVAL POSTGRADUATE SCHOOL
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THESIS

AN EVALUATION OF THE SPADS
AUTOMATED CLOUD ANALYSIS PROGRAM

by

Christopher A. Moren

March 1984

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The test results indicate considerable skill, particularly for cloud amount, cloud-top temperature and cloud-top height. The cloud type and precipitation intensity results were generally consistent but further testing is required to refine the thresholds and the standard deviation values for discrimination of particular cloud types.

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An Evaluation of the SPADS Automated Cloud Analysis Program

by

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ABSTRACT

An evaluation of the SPADS automated cloud and precipitation intensity analysis program is presented. The program uses the Geostationary Observational Environmental Satellite (GOES) visual and infrared imagery to produce contoured digital displays of cloud amount, cloud type, cloud-top temperature, cloud-top height and precipitation intensity for an approximate 1024 x 1024 n mi area centered at 35°N 80°W. Verification consists of correlating surface and upper-air observations, pilot reports, automated radar summaries and a manual analysis of the satellite imagery to the contoured digital display from the automated cloud analysis program for five cases during the summer 1983.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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I. INTRODUCTION

Satellite imagery has become an important tool for today's meteorologist. Significant sub-synoptic scale (10-1000 km) meteorological phenomena, not readily discernible through either synoptic or airway surface observations or 12-hourly upper-air reports, often can be determined from an interpretation of satellite imagery. Interpretation of satellite imagery, however important, is often neglected because of the excessive time required and the subjective nature of the analysis. Because of these constraints, operational meteorologists often rely on the imagery as a source of information for determining only the gross synoptic scale features, such as frontal placement, ridge axes and surface pressure centers. This does not adequately utilize the potential information available.

A detailed automated cloud and precipitation intensity analysis was prepared by Lieutenant Cynthia A. Nelson, USN for the Navy's interactive Satellite Data Processing and Display System (SPADS). Specifically, this program was designed to produce in real-time (15-30 minutes) analyses of particular important cloud and weather features, namely; cloud types, cloud amounts, cloud-top heights, cloud-top temperatures and precipitation intensity. This system collects and analyzes digital satellite data from the visual

and infrared channels which have a one-half hour temporal and 0.5 to 4.0 n mi spatial resolution respectively, from the Geostationary Operational Environmental Satellite (GOES) Visual-Infrared Spin Scanner Radiometer (VISSR).

The objective of this thesis is to evaluate the automated cloud and precipitation intensity analysis program utilizing the SPADS at the Naval Environmental Prediction Research Facility (NEPRF) in Monterey, California. Systematic evaluation of significant meteorological features will be conducted with available imagery, particularly GOES EAST, for regions in the southeastern United States. Verification data will consist of a subjective, manual analysis of the imagery with a correlation of surface observations, upper-air observations, pilot reports and the automated radar summary.

Chapter II consists of a review of the automated cloud and precipitation intensity analysis program. Chapter III will present the criteria and rationale for the evaluation, particularly the selection of satellite data, the regions covered, the establishment of the ground truth station network and the procedures for comparison of the automated computer program output to the subjective, manual satellite analysis, surface and upper-air observations, pilot reports and automated radar summary verifications. Chapter IV presents the case studies and results. Each case study includes a brief synoptic description, the output from the automated SPADS cloud and precipitation intensity analysis program,

the satellite images, the satellite nephanalysis and verification charts. Chapter V concludes the thesis by summarizing the automated cloud and precipitation intensity analysis program verification, and problem areas, and makes recommendations for further research projects.

II. CLOUD AND PRECIPITATION INTENSITY ANALYSIS

A. INTRODUCTION

The goal of the automated cloud and precipitation intensity analysis program is to provide an objective satellite analysis, yielding real-time analyses of cloud amount, cloud type, cloud-top temperature and height, and precipitation intensity. The SPADS automated cloud and precipitation intensity analysis model and program is a composite of previous work, namely, Liljas' (1981) cloud threshold and qualitative precipitation model, Reynolds and Vonder Haar's (1977) bispectral cloud-top temperature calculation, and Harris and Barrett's (1978) cloud amount estimate techniques. Additionally, a texture test for determining particular cloud types and a non-linear least squares curve fit for discriminating cirrostratus and altostratus was included. Each previous model input to the SPADS model is briefly described in the following sections.

B. SPADS AUTOMATED ANALYSIS MODEL DESCRIPTION

1. Cloud Type

The Liljas model (1981) utilizes the visual and infrared thresholds (a multi-spectral method which utilizes three sensor channels to type clouds and discriminate between water and land) from the TIROS-N Advanced Very High Resolution Radiometer (AVHRR). These thresholds were converted for the

GOES VISSR through the TIROS-N AVHRR temperature calibration table which yielded a rain cloud threshold of 251K. Only visual and thermal infrared aspects of the method are used due to the non-availability of the near-infrared channel in the GOES VISSR data. The procedure for calculating cloud type consists of calculating pixel array values for the average visual brightness, infrared brightness counts and the standard deviation of the cloudy visual counts (Fig. 1). The standard deviation values representing texture discriminates between stratiform and cumulus humulus, small and large cumulus congestus, and altostratus and cirrostratus. The initial standard deviation values (SIG_i) were approximated from the Harris and Barrett and Fye studies [Nelson, 1982] and establishes texture limits. Table I depicts the standard deviation values (SIG_i) and cloud coding schemes.

2. Cloud-Top Temperature/Height and Cloud Amount

The method for determining cloud-top temperature requires the calculation of the average cloud amount from the number of cloud decisions in the grid space (based on comparing the visual digital count of each pixel in the grid to a no-cloud threshold value) divided by the total number of pixels per grid space [Harris and Barrett, 1978]. Cloud-top radiance is given by combining cloud and ground portions using appropriate emissivities. The values for emissivity used are 0.55 for cirrus, 1.0 for nimbostratus and cumulonimbus and 0.9 for all other cloud types. Using Planck's function

a cloud-top temperature appropriate for scattered, broken and overcast situations is produced. These temperatures are subsequently compared to the representative upper-air soundings to yield cloud-top heights in millibars.

3. Precipitation Intensity

The Liljas model (1981) is used because it is an extension of his cloud typing method and requires little manipulation of previously derived inputs. When cumulonimbus or nimbostratus clouds are identified from the cloud type method, the precipitation intensity subroutine is called and produces an intensity profile of the precipitation (Fig. 2). The precipitation intensity categories are broken down according to the summation of the infrared radiance and the visual brightness, as illustrated by Table II. Liljas' model utilizes six categories [Liljas,1981]. Liljas adopted his precipitation thresholds from the results of Muench and Keegan (1979). The SPADS model utilizes three [Nelson, 1982], for light, moderate and heavy rainfall. The SPADS precipitation intensity categories are distributed into rainfall rates similar to the rainfall rates established by the surface observation rain/rainshower intensities, as inferred from Muench and Keegan (1979).

C. SPADS PROGRAM

The SPADS automated cloud and precipitation intensity analysis program is illustrated by Fig. 3. The infrared and visual satellite data fields are acquired from the GOES and

sixteen grid point upper-air soundings are obtained from Fleet Numerical Oceanography Center (FNOC) in Monterey, California. The upper-air and surface temperatures are obtained from the grid point upper-air profiles which are centered on each I,J position corresponding to the sixteen 64 x 64 infrared pixels.

After obtaining the GOES and FNOC data, the SPADS program is implemented and initially calculates the average visual brightness, standard deviation and cloud amount. From these values, the cloud types can be produced through the use of two tests, a comparison of the infrared and average visual counts and a texture test (standard deviation) as a supplement. If nimbostratus or cumulonimbus are identified in the cloud type section, the precipitation intensity portion of the program is initiated in order to determine a qualitative estimate of the intensity.

The cloud-top temperature and height portion of the program is initiated for all cloud cases and utilizes the FNOC upper-air soundings for temperature and height distributions.

Each portion of the program produces output for verification; cloud amount, cloud type, precipitation intensity, cloud-top temperature and cloud-top height. These are available for display, contouring or permanent file. The average visual brightness, standard deviation and the amount of cloud corresponding to each infrared pixel can be printed for validation, reference or further testing.

D. MODIFICATIONS

Modifications were made in order to facilitate running the SPADS program. Certain parameters can be adjusted without disruption of the basic program, for example, emissivity, image resolution, threshold values and variable satellite center point. These modifications were constructed to provide optimum flexibility for different users and their specific needs.

III. EXPERIMENT DESIGN

A. INTRODUCTION

The geographical location of this research is centered over the eastern United States (Fig. 4) with the center-point of the 512 x 512 grid located at 35°N 80°W. The digitized satellite data were acquired from the Geostationary Operational Environmental Satellite EAST (GOES EAST) by the NEPRF SPADS system. The geographic location was selected in order to:

- Maximize the coverage of significant meteorological phenomena;
- Maximize the surface and upper-air station verification data network and the meteorological observational pilot reports;
- Facilitate the satellite retrieval by NEPRF (GOES EAST); and
- Facilitate the utilization of the automated satellite cloud analysis program on the recently operational SPADS unit at the Naval Eastern Oceanography Center (NEOC) at Norfolk, Virginia.

B. EVALUATION INPUT DESCRIPTION

A cursory evaluation of the preceding east coast sector of the full disk GOES EAST images preceded the attempt to produce results with the automated cloud and precipitation intensity analysis program. The digitized satellite data are placed on tape for further processing by the automated cloud and precipitation intensity analysis program when

meteorological phenomena are prevalent throughout the geographic area. GOES visual and infrared data were extracted from the 1530 GMT image for local input to the SPADS. The data received were modified to provide a center point at 35°N 80°W on a 512 x 512 grid at 2 x 2 n mi visual resolution (infrared resolution 2 x 4 n mi) for an approximate 1024 x 1024 n mi area coverage.

Concurrently FNOC data fields were obtained for the model from the 1200 GMT analysis. Sixteen grid points, each centered on the sixteen 64 x 64 IR grids (128 x 128 VIS grids) were established. Surface and upper-level temperature profiles were extracted for each center point.

Concurrently, the verification data are acquired through an automated retrieval system. The surface observation verification data are acquired from the hourly airway observations. The 1200 GMT upper-air observations are utilized for the verification. As each satellite case study was selected, a surface, upper-air and pilot report network of verification data are selectively polled from the Automated Weather Network (AWN) and received via the Continental U.S. Meteorological Data System (COMEDS) to coincide with the satellite image time. The surface and upper-air station verification data network consists of approximately 62 surface stations and 22 upper-air stations scattered throughout the geographic study region, Table III. The Automated Radar Summary (ARS) Chart is received hourly on the half-hour from the National

Meteorological Center (NMC) via landline facsimile. The 1535 GMT ARS chart is utilized. A discussion of the verification data network inputs are described separately.

1. Surface Observations

The 62 surface observations are reported in airway code format. Location of the surface observation verification network is illustrated in Fig. 4. The 1500 GMT airway observations are utilized and are polled at 1530 GMT. These include a coded cloud group in the remarks section of the observation. The U.S. Department of Commerce (1980), illustrates the observation format and code group breakdown of the observation. Cloud type, cloud height, cloud amount and present weather are utilized for the surface verification data network.

When the code group for clouds are reported, the type of clouds are broken down into height classifications. In mid-latitudes the height boundaries are:

- low clouds (surface to approximately 6500 feet),
- middle clouds (approximately 6500 feet to 23,000 feet),
- high clouds (approximately 16,500 to 45,000 feet).

There is also a cloud priority within the cloud classification. For example, if two low clouds are observed, the highest priority is reported. The priority system is important to the verification, in that a type of cloud observed may not in fact be reported. In airway observation format, cloud amounts are cumulative and reported within the following groupings [U.S. Department of Commerce, 1980]:

- Clear (CLR) — No clouds
- Scattered (SCT) — Trace - 0.5
- Broken (BKN) — 0.6 - <1.0
- Overcast (OVC) — 1.0

Within the present weather section of the airway observations, the estimation of precipitation intensities are defined as follows [U.S. Department of Commerce, 1980]:

- Rain/Rainshower Intensities (in/h)

Light	Trace - 0.1
Moderate	0.11 - 0.3
Heavy	greater than 0.3

- Drizzle Intensity (in/h)

Light	Trace - 0.01
Moderate	greater than 0.01 - 0.02
Heavy	greater than 0.02.

2. Upper-Air Observations

The 22 upper-air observations are available for the verification region in standard radiosonde formatted code, U.S. Department of Commerce (1972) where the reports yield data on pressure surface altitude (meters), temperature (degrees Celsius), dew point depression, and the wind speed and direction at a constant pressure level. Fig. 4 depicts the upper-air observation verification network.

3. Pilot Reports

The pilot reports are formatted in accordance with Air Weather Service (1980). All available, pertinent pilot

reports are polled. These reports contain hourly significant meteorological information, where the message type indicates the severity of observation and the text elements describe the phenomena observed.

4. Automated Radar Summary Charts

The weather radar station network reports the radar observation in a digitized format. The observations are collected and processed by NMC at Suitland, Maryland for transmission as a facsimile product every hour. The ARS chart contours are drawn for echo intensity levels 1, 3 and 5 (light, heavy, extreme). Table IV illustrates the intensity classification. Echo tops are plotted as an underlined three-digit number in hundreds of feet. Echo bases are plotted as an overlined three-digit number.

It should be noted that the SPADS precipitation intensity analysis scheme utilizes the precipitation intensity levels for the surface observations as defined by the U.S. Department of Commerce (1980) which do not correlate with the precipitation intensity scheme associated with the ARS chart. The ARS chart precipitation intensity category 1 (light) nearly encompasses the light and moderate precipitation intensities catalogued by the SPADS analysis.

5. Manual Analysis of Satellite Images

The manual satellite analysis was performed by Capt. Al Shaffer, USAF, utilizing the infrared and visual satellite images for the determination of cloud type and cloud

amount boundaries. This analysis was conducted without the benefit of the surface observations.

C. VERIFICATION PROCESS

Each contoured display of cloud amount, cloud type, cloud-top height, cloud-top temperature and precipitation intensity produced by the automated cloud and precipitation intensity analysis program are verified through the following methods:

Contour Display	Verification Process
Cloud Amount/Type	Manual Analysis of Satellite Images, Surface Observations, Automated Radar Summary Chart
Cloud-Top Height/Temperature	Pilot Reports, Manual Analysis of Satellite Images, Upper-Air Observations, Automated Radar Summary Chart, Surface Observations
Precipitation Intensity	Automated Radar Summary Chart, Surface Observations

1. Cloud Amount/Type Verification Chart

Utilizing the manual satellite assessment with the surface observation (cloud amount and type code groups) and the ARS chart (echo intensity boundaries and echo precipitation types) supplement, a comparison of the cloud amount and type from the automated cloud and precipitation intensity analysis program was performed. The verification chart is composed of a regional depiction of cloud types and amounts

transposed on a comparable surface chart. This chart is then overlayed with the program output for comparison of cloud distribution and types.

2. Cloud-Top Height/Temperature Verification Chart

Utilizing a combination of the pilot reports, the ARS chart (echo precipitation tops), surface observations, upper-air observations and an enhanced infrared satellite image, cloud-top heights/temperatures are inferred. The verification technique applied requires the plotting of the pilot reports, echo precipitation tops and surface observations in order to obtain an estimate of the cloud-tops. Refinement of this estimate entails the use of selected upper-air observations that penetrate an area of clouds. Relative humidities, determined for each mandatory and significant level, are calculated as a guide for location of bases and tops of the cloud layers. Utilizing the dew-point depression profiles, cloud layers, bases and tops, are obtained [Air Weather Service, 1969]. Temperatures and heights can be extracted from the sounding for these layers. Further, temperatures from the enhanced infrared satellite image temperature scale can be selected for an area of clouds near one of the 22 upper-air data stations. Through this temperature and sounding, a height can be extracted. The method is similar to the cloud-top height analysis program except that manual analysis of radiosondes is used rather than the objective temperature analysis from FNOC. It is assumed that the temperature

changes vary slightly from the upper-air soundings at 1200 GMT to the satellite image time of 1530 GMT. These procedures are warranted, in that, the study takes place during the summer season where daily temperature changes are small through the upper atmosphere.

3. <u>Precipitation Intensity Verification Chart</u>

The cloud amount/type verification chart will also be utilized for the precipitation intensity verification. Information from the ARS chart on echo precipitation intensity are contoured for intensities 1, 3 and 5. Rainfall intensity and rates are determined by utilizing Table IV. The surface observations will provide a check of the precipitation intensity by indicating the actual precipitation occurring at an observation station.

IV. CASE STUDIES AND RESULTS

A. INTRODUCTION

The case studies will evaluate the accuracy, utility and timeliness of the SPADS cloud analysis. A brief synoptic description from the 1500 GMT analysis will precede each of the five case studies including the satellite images, verification charts and SPADS analysis. Conflicts or corroboration evident in each case will be described in the summary section of Chapter V. Data collection consists of capturing coincident infrared and visual data along with the verification data for 1530 GMT on 02 AUG 83, 11 AUG 83, 23 AUG 83, 31 AUG 83 and 02 SEP 83.

B. PRELIMINARY ANALYSIS

Two SPADS automated cloud and precipitation intensity program outputs for 11 AUG 83 and 23 AUG 83 were obtained in order to determine if corrections to the program were required and to ensure proper format. A SPADS contoured display of each output was attempted with moderate success. Cloud-top temperature, cloud-top height, cloud amount and precipitation intensity displays were marginally adequate. The cloud type was not contourable due to the non-consecutive nature of cloud type output numbers. Although marginal, the contoured displays from SPADS were not utilized for the analysis because of the individual scaling requirements for analysis

and the depiction of maximum and minimum values which eradicate contour definition. This produced the need for a hand analysis of the SPADS output. The data were produced and printed in a 64 x 64 array but due to printer limitations the size of the analysis does not correspond to the verification data charts or the satellite imagery. Horizontal and vertical reference lines are utilized on the SPADS output to outline quadrants of the data for verification.

1. Preliminary Analysis Run 1

Several inconsistencies were evident in the preliminary run. Each output error is described for cloud amount, cloud type/precipitation intensity and cloud-top height/temperature in the subsequent subsections.

a. Cloud Amount

The cloud cover threshold, five visual data brightness counts [Liljas, 1981], was modified by Nelson to 20 visual digital counts [Nelson, 1982]. The results produced for the test cases were unsatisfactory with the 20 visual brightness counts threshold. The 100% cloud cover area extended over regions that were clear on the satellite images and corroborated by clear surface observations. An adjustment to 22 visual digital counts was implemented which eliminated the cloud amount error. The modification was required since the data are from summer season and lower latitude producing a higher sun elevation and more illumination than previous experiments.

b. Cloud Type/Precipitation Intensity

The cloud type and precipitation intensity are coupled, in that the precipitation intensity subroutine is initiated only when the cloud type subroutine identifies nimbostratus/multi-layered clouds or cumulonimbus. Hence errors in the cloud type output result in errors in the precipitation intensity output. SPADS output of cloud type for 11 AUG 83 and 23 AUG 83 were not correct. Areas determined to be cloudy via the manual satellite analysis were recorded with no cloud type or an incorrect cloud type. For example, areas of cumulonimbus readily apparent on the satellite images and confirmed by surface observations were not registered by the SPADS analysis. In fact, cumulonimbus was not identified in the two cases. An inspection of the visual and infrared brightness counts were perplexing as the calculated values did not agree with values contained in the SPADS output of cloud type. Five possible explanations were examined:

- coding errors in the cloud type algorithm,
- averaging errors in the visual and infrared brightness counts,
- logic errors within the cloud type averaging,
- errors within the visual and infrared threshold limits,
- errors in the output manipulation.

Further analysis and code review determined that three errors existed. The cloud type thresholds for the Nelson study needed to be adjusted for the summer season as the limits determining cloud type were not consistent with

observed cloud types. Also there were subtle errors in the averaging and logic technique used for establishing the output for the SPADS display.

Nelson (1982) utilized a 0.5 n mi visual resolution data resulting in an 8 x 8 array of visual pixels per infrared pixel. A cloud decision (clear or cloudy) was made on each visual pixel. An average cloud amount for each 8 x 8 visual array was then determined and the average cloud brightness was compared with the corresponding infrared pixels to establish a cloud type for output in a 64 x 64 array required by the SPADS display.

The current model utilizes the same scheme except that 2 n mi visual resolution was used due to image data availability. The 2 n mi resolution allows a 2 x 2 array of visual pixels per infrared pixel. An average visual brightness count is calculated for each grid space. Through this visual average and infrared pixel value, a cloud type decision is achieved. The errors occurred while manipulating the data for SPADS display. Since SPADS requires a 64 x 64 array for display purposes, adjustment of the 256 x 256 array required a reduction by a factor of four. This was accomplished by averaging the 4 x 4 cloud type arrays. The averaged cloud type was then registered for output. This averaging technique was found to be inconsistent with cloud type decision processes. The solution to this inconsistency was accomplished before preliminary run 2 and is described in that section.

c. Cloud-Top Height/Temperature

Cloud-top height and temperature, utilizing the 20 visual brightness counts did not appear to be inconsistent with the verification technique. However, when the adjustment to 22 counts was required for the cloud amount output, improvement was evident in the second run of the initial testing.

2. Preliminary Analysis Run 2

A modified version of the cloud and precipitation intensity analysis program was produced. Output of cloud amount, cloud type/precipitation intensity and cloud-top height/temperature were consistent with expected results. Corrections which refined the program are described separately.

a. Cloud Type/Precipitation Intensity

The new cloud type thresholds were established after analysis of the visual and infrared digital counts for 11 and 23 AUG 83 (Fig. 5). The change in threshold values were initiated due to the case study occurring in the summer season and at a lower latitude where the sun elevation is higher producing increased illumination. Because of the threshold value changes, the standard deviation test values which discriminate between stratiform and cumulus humulus, small and large cumulus congestus and altostratus and cirro-stratus, were adjusted.

The averaging of the 4 x 4 cloud type arrays was not an appropriate decision process, since an average value

often does not yield the dominate cloud type or the most significant. This error was corrected by summing various cloud types for each of the arrays and the predominant cloud type is reported. In the case where two or more cloud types tie, a cloud type priority distribution, Table I, is used to show a single cloud type. The resulting SPADS analysis reasonably delineates the cloud types.

As a consequence of the adjusted cloud type thresholds, the precipitation intensity threshold values were also adjusted (Fig. 6). These categories are identified as the summation of the new infrared radiances and the average visual brightnesses, illustrated by Table V. The precipitation intensity area definition is consistent with the cloud typing model (nimbostratus and cumulonimbus identification) and in locating areas of rainfall which were verified by the surface observations and ARS charts.

C. CASE STUDY 1 (02 AUG 83)

1. Synoptic Description

A 1010 mb skagerraking low [Duthie, 1968] developed near the St. Lawrence river at the peak of the warm sector. The trailing cold front extended across the eastern New England states into New Jersey, Maryland, northern Virginia and northern Tennessee and Arkansas. Cold dry air flowing about a 1024 mb high near Lake Michigan and warm moist air about the Bermuda high produced an active frontal boundary.

2. Cloud Amount

The cloud amount estimates (clear, scattered, broken and overcast) and boundary definition from the SPADS analysis (Fig. 7) are satisfactory. The 02 AUG 83 case has several significant, clearly observable features:

- the cloud distribution across the Great Lakes, particularly, Lake Erie and Lake Ontario,
- the cloud distribution over Michigan, Wisconsin, Illinois and Indiana,
- the cloud distribution across the Gulf coast states, and
- the frontal cloud band location and orientation.

The cloud distribution over the Great Lakes region provides a unique test of the SPADS analysis program to map rapidly differing cloud amounts in the cold air mass behind the frontal boundary. Utilizing the GOES visual and infrared images (Figs. 8 and 9), the manual satellite analysis (Fig. 10), and the surface observations (Fig. 11) show that clouds are noticeably absent over the Great Lakes with significant cloudiness over the adjacent land areas. This is particularly evident over Lake Erie and Lake Ontario. The differing cloud amounts were correctly depicted and aligned by the SPADS analysis.

The cloud distribution over Michigan, Wisconsin, Illinois and Indiana is overestimated. The SPADS cloud amount analysis depicts the region as scattered with some isolated broken cloud cover. The verification data indicates the region to be clear with isolated scattered cloud cover.

This overestimation is slight due to the contouring scheme utilized for the cloud amount where:

- Clear 0
- Scattered 1 - < 60
- Broken 60 - < 100
- Overcast 100

The scattered regions often are misleading in that lower values from the SPADS could likely be classified as clear and in this region many of the values are in the low range (2-25).

Over the Gulf Coast, in the warm sector ahead of the cold front, the cloud amount distribution by the SPADS analysis was also excellent. Of particular merit was the depiction of the scattered region over southwestern Georgia, the overcast region over northern Florida and the scattered region over southern Alabama. The regions were aligned nearly exactly as depicted by the manual satellite assessment (Fig. 10). Another area satisfactorily analyzed was the ENE to WSW frontal orientation and general broadening of the frontal cloud boundary as depicted by Fig. 7. The region is depicted by SPADS as overcast whereas the verification data indicates broken cloud cover. Overestimation of cloud amount is again indicated.

The general cloud amount analysis is skillful, however overestimation of cloud amount is still evident and further adjustment of the cloud amount threshold is indicated.

3. Cloud Type/Precipitation Intensity

a. Cloud Type

Three cloud type areas are designated from the SPADS analysis (Fig. 12) for discussion; the frontal cloud types and the cloud types in the SE and NE quadrants. The manual satellite analysis (Fig. 10) and surface observations and ARS chart (Fig. 11) are reasonably consistent in that most cloud types identified by the manual satellite analysis are indeed corroborated by the surface reporting network.

The frontal cloudiness extends along an ENE-WSW line across the complete analysis region, broadening into a diffuse pattern near the western boundary (Figs. 8 and 9). In the eastern portion of the cold front, the SPADS analysis identifies areas of altostratus, stratus/fog, cumulus humilis, and cumulus congestus next to a broad area of nimbostratus/multi-layered clouds. A comparison of the SPADS analysis and the verification data yield the following characteristics.

The SPADS analysis of the nimbostratus/multi-layered clouds are verified by the manual satellite analysis as multi-heavy layered clouds. The cumulus congestus from the SPADS are verified by the region of cumulus and towering cumulus from the manual satellite analysis.

Over North Carolina and Virginia, the SPADS analysis depicts nimbostratus/multi-layered clouds with some altostratus along the northern periphery and cumulus congestus, cumulus humilis and stratus/fog along the southern

border. The manual satellite analysis indicates multi-layered cloudiness through the region with cumulus buildups to the south. The surface observations indicate multi-layered middle and high clouds (altostratus and cirrostratus) with scattered cumuliform just south of the central frontal cloud mass. The SPADS analysis of nimbostratus/multi-layered clouds is overdone.

In the western section of the analysis region along the broadening frontal boundary, the SPADS analysis identifies four dominant cloud types, nimbostratus/multi-layered clouds, cumulus congestus, stratus/fog and altostratus. Stratocumulus/thick fog, cumulus humilis and cumulonimbus are identified interspersed and along the dominant cloud type periphery. A comparison of the SPADS analysis and the verification data produced the following observations.

The SPADS analysis of the nimbostratus/multi-layered clouds in west central South Carolina and central Georgia is in agreement with the manual satellite analysis and the surface observation and ARS chart where multi-layered middle and high clouds predominate. The SPADS nimbostratus/multi-layered clouds in the southwestern portion does not verify with the manual satellite analysis where cumulus and towering cumulus are observed.

Over east central Mississippi, north central Alabama, southeastern Georgia and northern Georgia and South Carolina, the SPADS analysis depicts large areas of cumulus

congestus. The manual satellite analysis and surface observation and ARS chart verify the area and type definition.

Regions of stratus/fog over Tennessee as identified by SPADS are not verified by either the manual satellite analysis or surface observations, however, stratus/fog and stratocumulus/thick fog are verified extremely well over western North Carolina, southern Kentucky and west central West Virginia.

The SPADS depiction of altostratus over Tennessee and northern Alabama does not verify with the manual satellite analysis or the surface observations. However, both depict stratocumulus and altocumulus in the region indicating at least stratiform type and middle clouds. The SPADS depiction of the peripheral cloud types are in general agreement with the verification data, particularly, the cumulonimbus location and extent through southern Alabama and the Florida panhandle.

In the southeast quadrant the SPADS analysis depicts the cloudiness skillfully, identifying the several dominant cloud types; cumulonimbus, nimbostratus/multilayered clouds, cumulus congestus and adjacent cumulus humilis as established by the manual satellite analysis. The stratiform cloudiness analyzed by the SPADS along the periphery of the central cloud mass is inconsistent with the obvious convection. The problem may be with the standard deviation values established for discriminating between stratus/fog

and cumulus humilis and particularly altostratus and cirrus/ cirrostratus. For example, an area immediately to the west along the border of the cloud mass is clearly cirrus. The SPADS analysis depicts altostratus.

In the northeast quadrant three types of clouds dominate the SPADS analysis; stratiform, cumuliform and multi-layered clouds. The surface observations and the manual satellite analysis confirm the area and type skillfully. Peripheral stratus/fog identified by the SPADS analysis in the southern boundary of the cloud mass is not confirmed by the surface observations. In the main cloud mass cumuliform cloudiness (cumulus humilis and cumulus congestus) as analyzed by the SPADS is confirmed by the surface observations.

Although the SPADS analysis provides a reasonable depiction of the cloud types, particularly cumulus congestus and cumulonimbus, problems appear to exist within the stratus/ fog and cumulus humilis discrimination. The problem is the standard deviation test values that determine the cloud type reported. Further study of the standard deviation tests are indicated.

b. Precipitation Intensity

Due to the method of verification using the ARS chart and surface observations, oceanic regions cannot be verified as the ARS chart does not extend beyond approximately 200 n mi of the coastline and there are no ship surface observations included in this study.

Three areas are within the verification framework (Fig. 13); the frontal boundary, the southwest quadrant and eastern Florida and the intercoastal sections of Georgia and South Carolina.

The frontal boundary is clearly identified by SPADS, however, the precipitation intensity is considerably overestimated and the area coverage is entirely too large.

The precipiation intensity in the southwestern quadrant is depicted quite adequately by the SPADS analysis. The area definition is similar to the ARS chart and the surface observation from Mobile, Alabama indicates cumulonimbus and rainshowers to the west. The SPADS precipitation intensities are representative of the ARS chart intensity contours 1 (light) and 2 (heavy).

The areas over eastern Florida and the intercoastal region of Georgia and South Carolina are depicted on the ARS chart but are weakly identified by the SPADS analysis.

4. <u>Cloud-Top Temperature/Height</u>

a. Cloud-Top Temperature

The SPADS analysis of the cloud-top temperature is not easily verified except through an independent upper-air analysis of individual plotted radiosonde soundings where temperatures are established at the analyzed top of the cloud layer. Cloud-top temperature values can be inferred appropriate for selected cloud types and bases, in that low clouds denote warmer temperatures whereas high clouds denote colder temperatures.

Six upper-air soundings were selected from the 22 available. Cloud-top temperature/height values are manually analyzed from the six soundings. These results, plus the surface observations (cloud bases), the ARS chart (echo bases/tops), the pilot reports (bases/tops) and the SPADS output are reported in Table VI.

The SPADS analysis of the cloud-top temperature (Fig. 14) is skillful. Three areas are designated for study; the western portion of the northwest quadrant over Wisconsin, Lake Michigan, Illinois, Indiana, western Tennessee and western Michigan, the frontal boundary extending across New Jersey, Maryland, northern Virginia and Tennessee and the region over the western Florida panhandle and southern Alabama.

In the western portion of the northwest quadrant, the SPADS cloud-top temperature analysis depicts a range of temperature values from 260K to 340K. Temperature values above 290K are clearly indicative of surface temperature values. These surface temperatures dominate the region. The small areas where the temperature values range from 260K to 290K are associated with low clouds and are located over northwestern Wisconsin and eastern Ohio where the surface observations and satellite images depict low clouds. Inordinately warm cloud-top temperatures (310K) are instances where the brightness count values are obtained over clear or near clear skies. These values will invariably yield extremely low heights (correspondingly high pressure values on the order of 1200 mb

to 1600 mb) in the cloud top height portion of the program output. Boundary limits established for the surface and upper atmosphere will preclude inclusion in future cloud analysis programs. The surface observations and ARS verification chart (Fig. 11) depict clear skies to thin scattered high clouds.

In the frontal boundary, the SPADS analysis indicates a range of cloud-top temperatures from 220K to 320K. The surface observations depict a wide variety of cloud layers and types. While not completely verifying the SPADS analysis, the surface observations do not dispute the wide range of cloud-top temperature fluctuations. Four of the six selected upper-air soundings were within the frontal zone; Wallops Island, Virginia, Greensboro, North Carolina, Athens, Georgia and Centreville, Alabama. The maximum height variation from the SPADS analysis to the upper-air analysis verification data is 50 mb at Athens, Georgia (station 72311-AHN) and a minimum of 5 mb at Centreville, Alabama (station 72229-CKL) and Wallops Island, Virginia. The output from SPADS appears to skillfully map the cloud-top temperatures.

In the region over the western Florida panhandle, the SPADS cloud-top temperature analysis depicts a range of temperature from 200K to 280K. The area is largely covered by temperatures below 240K indicating considerable amounts of high clouds, probably cumulonimbus. The surface observation from Mobile, Alabama reports cumulonimbus occurring at the station and cumulonimbus to the west. The ARS chart indicates

echo tops from 42,000 to 46,000 ft in the region. In this area, the SPADS analysis is verified excellently.

b. Cloud-Top Height

The cloud-top height analysis (Fig. 15) from the SPADS follows as a function of the SPADS cloud-top temperature. Therefore, any significant deviation from the cloud-top temperature analysis would not be expected. The same regions discussed previously in the cloud-top temperature analysis were examined for variations. None were noted. The cloud-top height distribution in all three regions agree with the available verification data.

One additional region, east and northeast of the Bahama Islands was significant. The manual satellite analysis indicated a large area of overcast cumulonimbus. The SPADS analysis depicts a range of cloud-top heights from 50 to 200 mb (70,000 ft to 40,000 ft) which is generally consistent with the manual satellite analysis depiction of cumulonimbus. The values of the cloud-top heights less than 200 mb are suspect because the values are generated by a nearly isothermal profile in the stratosphere resulting in uncertain cloud-top heights. Boundary limits could be established for the surface and upper atmosphere. The SPADS cloud top temperature/height analysis is reasonable and consistent with the verification inputs.

D. CASE STUDY 2 (11 AUG 83)

1. Synoptic Description

A 1003 mb low pressure center is located over Lake Ontario. A cold front extends from the low through central Ohio, southern Indiana and Illinois, south-central Missouri and southern Kansas. A warm front extends from the low through northwestern New York, northern Pennsylvania and southern Connecticut. The Bermuda high extends over the southeastern United States.

Continental polar air (cP) flowing from northern Canada is being funneled southward by a 1023 mb high pressure center over northern Minnesota. Warm moist tropical air (mT) is flowing over the central eastern United States. These air masses produce instabilities with resultant clouds and weather activity across the middle of the region.

2. Cloud Amount

The SPADS analysis of the cloud amount boundaries (Fig. 16) is satisfactory, particularly the alignment and location. The cloud amount definition is excellent but overestimated. Several examples are described.

The satellite images and surface observations, Figs. 17, 18 and 19, respectively depict areas over Georgia, southern Alabama and Mississippi as clear to scattered, whereas the SPADS analysis of the cloud amount is scattered to broken. The clear slot immediately behind the cold front through south-central Indiana and Illinois was indicated but as an

area of broken to scattered clouds (Fig. 16) whereas clear to scattered conditions exist.

The region through southern North Carolina, South Carolina and adjacent coastal waters are clear to scattered, as verified by the satellite images (Figs. 17 and 18), manual satellite analysis (Fig. 20), and the surface observations (Fig. 19). The SPADS analysis overestimates the cloud amount.

The problems of overestimation of cloud amount is quite likely due to the cloud amount threshold which was adjusted to 22 visual counts from the Nelson model threshold of 20 and the definition of scattered clouds discussed earlier.

3. <u>Cloud Type/Precipitation Intensity</u>

a. Cloud Type

The description of the SPADS analysis (Fig. 21) is broken down into several separate regions. One distinctive area is associated with the frontal boundary extending across the northern analysis region. The other regions are found in the southern half of the analysis region and are convective in nature.

The frontal boundary is located over the northern section of the analysis area with a broad area of various cloud types associated with the warm front on the northeast section and a clear distinction of prefrontal clouds, frontal clouds and post frontal cloudiness in the northwestern section.

The northeast portion of the SPADS analysis contains three dominant cloud types; nimbostratus/multi-layered

clouds, cumulus congestus and altostratus. Stratus/fog, stratocumulus/thick fog, cumulonimbus and cumulus humilis are found on the boundaries of the dominant cloud type areas. The surface observations indicate stratus and stratocumulus along the boundaries with multi-layered cloudiness (altocumulus and cirrostratus) through the major cloud mass area. The manual satellite analysis verifies the cumulus congestus and altostratus. Stratus areas defined by the SPADS analysis encompasses too large an area.

The northwest portion of the SPADS cloud type analysis consists primarily of stratiform low clouds (stratus and stratocumulus), cumuliform (cumulus humilis, cumulus congestus and cumulonimbus) and nimbostratus/multi-layered clouds. This area is further broken down into three distinct regions; post frontal, frontal and prefrontal.

The SPADS cloud type analysis identifies stratiform clouds with scattered areas of cumulus in the post frontal region which is verified well by the manual satellite analysis and the surface observations. A region of nimbostratus/multi-layered clouds with cumulus congestus over Michigan is verified by the manual satellite analysis. The surface observations do not support the multi-layered clouds but do confirm the presence of towering cumulus.

The SPADS depiction of the cloud types in the frontal zone is good. The detection of cumulonimbus is consistent with the surface observations and manual satellite

analysis. The peripheral stratocumulus, cumulus humilis and cumulus congestus are typical of the verification data. The nimbostratus/multi-layered clouds are overestimated but representative. The verification data indicates more altostratus and cirrostratus. The SPADS analysis does not identify the altostratus and cirrostratus except as multi-layered cloudiness.

The prefrontal cloud types from the SPADS cloud type analysis indicates stratiform clouds. This area extends from western Virginia to northern Alabama and represents the strong southerly flow ahead of the cold front. The northernmost portion of the prefrontal clouds as verified by the manual satellite analysis confirms the existence of stratiform clouds. The rest of the SPADS prefrontal cloudiness region is incorrectly identified as stratus, stratocumulus and altostratus. The verification data defines the region as cumuliform.

In the southern portion of the analysis region three distinct areas are defined by the SPADS analysis; southeast of the North Carolina coast, east of the Florida-Georgia border and over north central Florida.

In each region, the SPADS analysis depicts a large area of nimbostratus/multi-layered clouds and small areas of cumuliform and stratiform clouds. The verification data indicates the regions as predominantly cumuliform with some multi-layered cloudiness. In this case the SPADS analysis of the cloud type is successful. The cloud types depicted by the SPADS as cumuliform generally are verified, however, stratiform

and nimbostratus/multi-layered cloud areas are commonly overestimated. This is probably due to the threshold delimiters and standard deviation test values which determine a specific cloud type. It appears that the standard deviation test for cirrus/cirrostratus and altostratus is in error as the cirrus/cirrostratus is rarely depicted by the SPADS analysis when it is clearly indicated by the surface observations and manual analysis.

b. Precipitation Intensity

The SPADS precipitation intensity analysis (Fig. 22) follows from the areas identified as nimbostratus/multi-layered clouds and cumulonimbus from the SPADS cloud type analysis. Six areas are detected; the frontal zone, an oceanic convective area in the southeastern portion of the northeast quadrant, an area southeast of the North Carolina coast, an area east of the Florida-Georgia border, north central Florida and the near coastal region of Florida, Alabama and Mississippi. The second area could not be verified due to the limitations of the verification data.

The frontal zone precipitation area definition by the SPADS analysis is excellent. The SPADS analysis even discerned the absence of precipitation over western Pennsylvania. The SPADS analysis depicts all three intensities (light, moderate, heavy). The ARS chart (Fig. 19) encompasses the SPADS precipitation intensity analysis by its contour of heavy precipitation intensity and verifies the SPADS analysis.

The area depiction of the regions southeast of North Carolina, east of the Florida-Georgia border and over north central Florida are consistent with the verification data. The SPADS precipitation intensity analysis is corroborated by the ARS chart (Fig. 19).

The precipitation intensity area located over the near coastal region of northwest Florida, Alabama and Mississippi by the SPADS analysis is consistent with the manual analysis and the surface observations. The precipitation intensity definition and intensity level determination concurs with the verification data.

4. Cloud-Top Temperature/Height

a. Cloud-Top Temperature

Three regions from the SPADS cloud-top temperature analysis (Fig. 23) were selected for examination; the western frontal boundary over southern Indiana and Ohio, the region over Wisconsin, Lake Michigan and Michigan and the region in advance of the front over central Kentucky and western Tennessee. Each of these regions are representative of the study region in general and provides a test of the cloud-top analysis capability.

In the western frontal boundary, the SPADS analysis depicts ranges of cloud-top temperature from 200K to 280K. The GOES visual and infrared imagery (Figs. 17 and 18) indicate a bright well-defined cloud region indicative of thick, multi-layered high clouds, probably cumulonimbus. The surface

observation and ARS verification chart (Fig. 19) indicates cumulonimbus at Cincinnati, Ohio (station 72420-CVG) and echo tops ranging from 35,000 to 40,000 ft. The temperature inferred from the verification data clearly corroborates the SPADS analysis. Also, the SPADS location and orientation is noteworthy.

In the region over Wisconsin, Lake Michigan and Michigan, the SPADS analysis of cloud-top temperature depicts ranges of 250K to 300K. The satellite images indicate a region of low to middle clouds and thus the temperature values should be warmer and near the surface values. The cloud-top temperature/height verification table, Table VII, includes two upper-air observations within the region, Green Bay, Wisconsin (station 72644-GRB) and Flint, Michigan (station 72637-FNT). The SPADS analysis differs from the upper-air temperature analysis by 8K. The surface observations in the region indicate low clouds (stratus/stratocumulus and cumulus) and pilot report number 1 indicates cloud bases of 5700 ft. These cloud types and bases combined with the manual satellite analysis confirm the low cloud inference made by the SPADS analysis over the region.

In the region in advance of the front over central Kentucky and western Tennessee, the SPADS analysis depicts a range of cloud-top temperatures from 280K to 350K. The inference from the SPADS analysis, is that the region contains clear skies to scattered low clouds. The surface observations

indicate clear to scattered cloudiness within the region. Thus the temperature as analyzed by the SPADS verify well except for the spurious warm surface temperatures over the clear areas.

b. Cloud-Top Height

The SPADS cloud-top height analysis (Fig. 24) is divided into two regions for examination; the post frontal zone over Wisconsin and Lake Michigan and the region over Kentucky, Tennessee and western North Carolina.

In the post frontal zone, the SPADS analysis indicates low and middle cloud heights with ranges of values from near surface to 600 mb. The surface observations indicate low clouds with some middle clouds. Pilot report number 1 indicates bases at 5700 ft, approximately 800 mb. In Table VII, the upper-air observations from Green Bay, Wisconsin and Flint, Michigan indicate low clouds with the SPADS analysis values differing by 68 mb to 30 mb respectively. The verification data corroborates the SPADS cloud top height analysis in this region.

In the region over Kentucky, Tennessee and western North Carolina, the SPADS cloud-top analysis correctly discriminates the height boundaries present. In the frontal zone to the north, 700 mb to 500 mb values are indicated. In the clear region immediately ahead of the frontal cloudiness, cloud-top heights of near 1000 mb are indicated. The low cloud band in the southerly flow ahead of the front, the

cloud-top height values range from 850 mb to 700 mb. The cloud-top height analysis is skillful in this region.

In general, the SPADS analysis of the cloud-top temperature/height distribution is excellent. Areas are reasonable and consistent with the available limited verification data set. Partly cloudy regions may tend to be a problem in that the SPADS analysis indicates low heights in clear regions and surface values in scattered cloud regions. This does not appear to be a major problem since cloud orientation and definition generally verifies well.

E. CASE STUDY 3 (23 AUG 83)

1. Synoptic Description

A quasi-stationary front extends across central Virginia, southern West Virginia, Kentucky, western Tennessee and northeastern Arkansas. The Bermuda high does not ridge over the southeastern United States in this case. A complex 1025 mb high pressure system over Canada advects modified polar air into the northern United States while a weak 1017 mb low pressure center is discernible over south-central North Carolina with troughing to the southwest. Cold, dry continental polar air (cP) flows into the northeastern United States as warm moist tropical air (mT) is advected weakly into the southern United States. The frontal boundary cloudiness is clearly discernible to the north of the front.

2. Cloud Amount

The SPADS cloud amount depiction (Fig. 25) is skillful. The location of cloud masses and their orientation is excellent, however the analyzed cloud amount is overestimated. Regions over the Gulf coast states, positively identified as clear by the satellite images (Figs. 26 and 27), manual satellite analysis (Fig. 28) and the surface observations (Fig. 29) are analyzed as clear to scattered to broken by the SPADS analysis. Regions over the Great Lakes, however, are analyzed well.

3. Cloud Type/Precipitation Intensity

a. Cloud Type

Five SPADS cloud type areas (Fig. 30) are designated for verification; the frontal cloud type boundary, the cloud types in the extreme northeast quadrant, the northwest quadrant, the southern portion of the study area and the east central portion of the study region just off the Carolina coast.

The frontal boundary extends across the northern portion of the study region aligned nearly east to west. The SPADS analysis depicts a large region of cumulus congestus extending along the quasi-stationary front with stratiform clouds generally dominating the boundary of cumulus congestus. Some cumulus humilis is also depicted.

The verification data does not verify the extensive region of cumulus congestus. Both the manual satellite analysis

(Fig. 28) and surface observations (Fig. 29) indicate extensive regions of multi-layered mid clouds, stratus and stratocumulus. The peripheral stratiform clouds and isolated/scattered cumulus humilis indicated by the SPADS analysis verifies well.

The stratiform cloud types indicated by the SPADS analysis in the extreme northeast quadrant over New England do not verify. The manual satellite analysis and surface observations indicate cumuliform clouds.

The cloud types identified by the SPADS analysis in the extreme northwest quadrant over northern Wisconsin and northern Michigan and Lake Superior are cumulus congestus, stratus/fog, stratocumulus/thick fog, altostratus and nimbostratus/multi-layered clouds. Except for the overestimation of the cumulus congestus area, this region was successfully analyzed. The SPADS analysis depicts the area over central Wisconsin, northern Illinois, Lake Michigan and southern Michigan as clear. Thin cirrus is indicated by the surface observations.

The southern quadrants, east northeast of the Bahamas, southern Florida and the Gulf of Mexico, as analyzed by the SPADS, contain large areas of nimbostratus/multi-layered clouds and cumuliform clouds with altostratus and stratus/fog interspersed. This agrees with the verification data except that the altostratus and stratus/fog appear to be incongruous in these convective cloud situations. For example, the region across north central Florida is analyzed by SPADS as

stratus/fog and altostratus whereas the surface observations and manual satellite analysis indicates cumulus and cirrus. Also, SE of Miami, Florida cirrus blowoff from cumulonimbus is evident on the satellite images whereas the SPADS analysis indicates altostratus. The potential for altostratus formation in this region is not likely since as the cumulonimbus spreads and dissipates the cloud type generally encountered is altocumulus which should be recorded by the SPADS as nimbostratus/multi-layered cloudiness.

In the east central portion of the study area, the SPADS analysis depicts a broad area of nimbostratus/multi-layered clouds with peripheral stratiform and cumuliform cloudiness. The manual satellite analysis verifies the region extremely well.

b. Precipitation Intensity

The SPADS precipitation intensity analysis (Fig. 31) depicts two large regions of precipitation. One region, east of the Bahamas in the southeast quadrant, can not be verified due to its distance from the reporting radar station network. The region near the east coast of North Carolina is verified by the surface observations (Fig. 29) where a light rainshower is occurring at Cape Hatteras, North Carolina and a broad area of light intensity precipitation is indicated by the ARS analysis. The magnitude of the precipitation intensity as depicted by the SPADS analysis, however, is more intense than the reporting surface observation.

Three regions indicated on the surface observation and ARS verification chart are not depicted by the SPADS analysis; an area of moderate precipitation over Maryland, northern Virginia, and West Virginia, an area of light precipitation over western and southern Illinois and southern Indiana and an area of light precipitation over southern Florida. Only two small precipitation regions are isolated over Kentucky by the objective program.

In each case cumulus congestus is analyzed by SPADS and since the precipitation intensity portion of the SPADS program is not initiated unless cumulonimbus or nimbostratus/multi-layered clouds are present, no precipitation intensity values were obtained by the SPADS analysis. The visual and infrared threshold values for these cloudy areas were not sufficient to produce output in the cumulonimbus or nimbostratus/multi-layered cloud categories. Also, a comparison of the cloud-top temperature values in the region are relatively warm at 260K to 280K.

4. Cloud-Top Temperature/Height

a. Cloud-Top Temperature

Two regions from the SPADS cloud-top temperature analysis (Fig. 32) are identified for discussion; a region over northern Virginia, western Maryland, southern Pennsylvania and northern West Virginia and a region over central North Carolina, South Carolina and north central Georgia.

In the first region, the SPADS analysis depicts a range of values from 240K to 280K. The cloud-top

temperature/height verification table, Table VIII, includes one upper-air observation in the region from Washington-Dulles, Virginia (station 72403-IAD). The SPADS analysis differs from the upper-air observation verification analysis by 11 mb. Also, the surface observations in the region indicate multi-layered low, middle and high clouds inferring a broad range of cloud top temperatures. The SPADS analysis showed reasonable accuracy in this area.

In the second area, the SPADS analysis depicts ranges of cloud-top temperatures from 260K to 360K. The 280K contours are very small and located over the Appalachian mountains in northern Georgia. These temperatures are indicative of low to middle clouds which are visible on the satellite images (Figs. 26 and 27). The rest of the region is clear or has scattered thin cirrus as indicated by the surface observations and manual satellite analysis. Again, warm temperatures (360K) over the clear areas are found with no detection of the thin cirrus. The SPADS analysis of these two areas is good and is representative of the whole study region.

b. Cloud-Top Height

The SPADS cloud-top height analysis (Fig. 33) reaffirm the results of the cloud-top temperature analysis. Over the mid-Atlantic states, cloud-top heights range from 700 mb to 300 mb indicative of low, middle and high clouds which are reported by the surface observation data network. Over the Carolina, Georgia region, the SPADS analysis depicts surface values.

The SPADS analysis of the cloud-top temperature/height is very skillful. The cloud-top temperature/heights are clearly in agreement with the reported surface observations of cloud types and bases and the manual satellite analysis cloud types.

F. CASE STUDY 4 (31 AUG 83)

1. Synoptic Description

A weak 1011 mb closed low is centered over New Hampshire. A cold front extends from the low through southeastern New York, east-central Pennsylvania, central West Virginia to an open 1012 mb low over northern Kentucky continuing to a weak 1012 mb low over western Tennessee/western Arkansas. A weak 1011 mb closed low is centered at 28°N 87.5°W in the Gulf of Mexico and a 1022 mb high is centered over northwestern Wisconsin.

Modified continental polar air (cP) is being slowly drawn into the north-central United States while maritime tropical air (mT) is being advected across the Florida panhandle. The frontal boundary is weakly defined in the surface data.

2. Cloud Amount

The SPADS analysis of the cloud amount (Fig. 34) is excellent yielding strong correlation with cloud alignment and location. A slight overestimate of the cloud amount is found in one area.

Over southeastern North Carolina and north-central South Carolina, the SPADS analysis depicts two overcast regions which are conspicuously scattered to broken on the satellite

images (Figs. 35 and 36), the manual satellite analysis (Fig. 37), and the surface observations (Fig. 38). Pilot report 10 on Fig. 38 reports the sky condition as scattered with ceiling and visibility unrestricted above flight level. The SPADS cloud amount analysis is good over the Great Lakes region where scattered clouds are clearly discernible over Lake Erie and Lake Ontario from the satellite images (Figs. 35 and 36) and the manual satellite analysis (Fig. 37).

3. Cloud Type/Precipitation Intensity

a. Cloud Type

Two cloud type areas as analyzed by the SPADS analysis (Fig. 39) are designated for verification; the frontal boundary and an area in the southern quadrant.

The frontal boundary extends across the northern portion of the study region and is aligned ENE to WSW. In the eastern portion the SPADS analysis depicts extensive stratiform (stratus/fog and stratocumulus/thick fog) in the extreme northeast quadrant with cumuliform and nimbostratus/multi-layered clouds throughout the central portion of the frontal cloud zone. Residual stratus/fog and altostratus are indicated to the south of the frontal boundary. The verification data are supportive of each area defined by the SPADS analysis. There is doubt to the amount of nimbostratus/multi-layered cloudiness as the surface observations (Fig. 38) report cumulus, towering cumulus, stratocumulus, altostratus and cirrus. Also, there is some doubt concerning the area of

stratus and altostratus over the southern boundary of the frontal zone where the manual satellite analysis (Fig. 37) indicates cumulus, embedded towering cumulus and altostratus and the surface observations indicate altocumulus and cirrus.

In the western portion of the frontal boundary, the SPADS analysis indicates a broad area of cumulus congestus, nimbostratus/multi-layered clouds and stratus/fog with some cumulus humilis, stratocumulus/thick fog and altostratus. The manual satellite analysis and surface observations verify the SPADS analysis well. The problem areas are the extent of the nimbostratus/multi-layered clouds and the stratus/fog identification. The nimbostratus/multi-layered clouds appear to be a catch-all for multi-layered clouds even though types identifiable by the cloud type program are present. The stratus/fog areas identified by the SPADS are generally in regions where stratiform clouds exist but the predominant stratiform cloud identified by the verification data is stratocumulus.

In the southern quadrant, the SPADS analysis frequently identifies altostratus when cirrus and thin cirrus is clearly indicated by the satellite images (Figs. 35 and 36) and the manual satellite analysis, particularly in the southeastern portion, east of the Bahamas. The verification is excellent in regions where the SPADS analysis indicates cumulus congestus, cumulus humilis and cumulonimbus. Nimbostratus/multi-layered clouds, again, appear to be inclusive of all cloud types that have some multiple layering through the middle cloud level.

In general the overall verification is fair with excellent location and identification of the cumuliform clouds but poor identification of the cirrus/cirrostratus.

b. Precipitation Intensity

There are two main areas featured by the SPADS precipitation intensity analysis (Fig. 40); the eastern frontal boundary and the western frontal boundary. Secondary precipitation intensity areas are also depicted in the southern quadrants.

In the eastern frontal region, over the northeastern U.S. through Massachusetts, Rhode Island, Connecticut, Pennsylvania, northern West Virginia and central Ohio, the SPADS precipitation intensity analysis verifies well with the ARS chart outline of intensity. The surface observations indicate light to moderate rainshowers and the SPADS analysis indicates light to moderate intensities. In the western portion of the SPADS analysis, a region of light to moderate precipitation is indicated. The ARS chart does not depict a radar echo contour in the region, however, Memphis, Tennessee, reports occasional light rain which lies in the area defined by the SPADS analysis. In this particular instance the SPADS precipitation intensity analysis is more representative than the ARS chart. The ARS chart may not have had the area contoured because the intensity of the rain was too light for radar analysis. In the southern quadrants, the SPADS precipitation analysis verifies generally well, in that the areas depicted coincided

with areas identified by the ARS chart. Precipitation was not reported by the surface observation data station network in the southern quadrants.

4. Cloud-Top Temperature/Height

a. Cloud-Top Temperature

Two regions from the SPADS cloud-top temperature analysis (Fig. 41) are utilized for discussion; a region over central and northern Ohio and western Pennsylvania and a region over Tennessee and western Kentucky. These areas encompass broad areas of cloudiness at differing levels and are representative of the study region in general.

The SPADS analysis of the region over central and northern Ohio and western Pennsylvania depict ranges of cloud-top temperatures from 220K to 280K. The GOES infrared satellite image (Fig. 36) clearly depicts a very bright sharply defined area of high clouds inferring colder temperatures. Table IX illustrates the radiosonde observation of Pittsburgh, Pennsylvania (station 72520-PIT) which lies within the region with a cloud-top temperature of 263K whereas the SPADS analysis yielded 262K. The surface observations are inconclusive as a low and middle overcast obscures the higher cloud layers, thus no inference is made about cloud-top temperature. The ARS chart, however, indicates echo tyops of 40,000 to 41,000 ft. The verification data supports the SPADS analysis definition of colder temperatures.

In the region over Tennessee and western Kentucky, the SPADS cloud-top temperature analysis depicts temperature

ranges from 220K to 280K. The GOES infrared satellite imagery (Fig. 36) depicts a bright, broadly diffuse area indicating middle and high clouds. The surface observations indicate middle and high clouds with some towering cumulus evident. The manual satellite analysis (Fig. 37) depicts a region of thin cirrus and altostratus. From this data cooler temperature inferences can be made. Table IX illustrates the analyzed upper-air cloud-top temperature from Nashville, Tennessee (station 72327-BNA) of 268K. The SPADS analysis for the same area produced a temperature of 258K. The verification data supports the cloud-top temperature distribution and orientation.

b. Cloud-Top Height

The SPADS cloud-top height analysis (Fig. 42) is verified extremely well. Regional depiction of surface values to upper level values are consistent with the verification data depiction of clear skies to thick high clouds. For example, the region over southern and southwestern Alabama is clear as verified by the surface observations and manual satellite analysis. The SPADS cloud-top height analysis indicates a region of 1000 mb or greater. Cumulonimbus depiction over southwestern Florida and coast are accurately described with height values of 300 mb to 200 mb.

In general the SPADS analysis of the cloud-top temperatures/heights is excellent. Particular merit is noted for the definition of the cloud-top temperatures/heights over clear areas and regions covered by cumulonimbus and dense high clouds.

G. CASE STUDY 5 (02 SEP 83)

1. Synoptic Description

A 1010 mb open low is centered over northeastern Florida. A 1020 mb high is located over central Pennsylvania and cold moist air from the east of the high and warm moist air from the open low and the Bermuda high is directed westward to the central eastern seaboard. The resulting frontal boundary is broad and diffuse.

2. Cloud Amount

The SPADS analysis of the cloud amount (Fig. 43) is excellent. Location, orientation, and amount are consistent with the verification data. The cloud depiction over the southeast quadrant was particularly well done. These areas of broken to overcast clouds are observed in the southeast quadrant on the satellite images (Figs. 44 and 45) and the manual satellite analysis (Fig. 46). The areas are comma shaped and aligned nearly north to south. The SPADS analysis resolved the location, alignment and amount well.

3. Cloud Type/Precipitation Intensity

a. Cloud Type

The SPADS cloud type analysis (Fig. 47) identifies two regions; a broad area encompassing the east central region and the southern quadrants and an area in the extreme north central portion of the study region.

In the east central and southeastern portions, the SPADS analysis identifies predominantly nimbostratus/multi-layered clouds, cumulonimbus, altostratus, and cumulus

congestus. Scattered throughout the cloud mass are cumulus humilis, stratus/fog and stratocumulus/thick fog. The manual satellite analysis (Fig. 46) and the surface observations (Fig. 48) verify the region of cumulonimbus excellently and the regions of nimbostratus/multi-layered cloud and cumulus congestus well. There is doubtful verification of the alto-stratus and stratus/fog in the southern extremes where cumulus and scattered stratocumulus are indicated by the manual satellite analysis. In the northern boundary the altostratus and stratus/fog analyzed by SPADS are also in doubt. Stratiform clouds predominate but cirrostratus appears to be the dominant type. There may be an adjustment required in the texture test for discriminating altostratus and cirrostratus. The cumulus humilis reported by SPADS is, in general, in agreement with the verification data; however, the area extent appears to be too small.

In the western and southwestern portions, the SPADS analysis identifies predominately nimbostratus/multi-layered clouds, cumulus congestus and stratocumulus/thick fog. Along the periphery stratus/fog, altostratus, cumulus humilis and cumulonimbus are indicated. The low and middle stratiform clouds verify well, as well as the cumulonimbus. The nimbostratus/multi-layered clouds are generally excessive in extent and are reported when multi-layered clouds are present when cloud types that should be discernible by the SPADS analysis program are not. The cumulus congestus

extending through the central cloud type mass as analyzed by the SPADS does not verify. The surface observations and manual satellite analysis depict stratus, stratocumulus, altostratus and altocumulus.

In the extreme north central portion of the study region, the SPADS identifies nimbostratus/multi-layered clouds, cirrostratus, altostratus, stratus/fog and isolated cumulus congestus. The verification data confirms the SPADS cloud type breakdown, location and general extent.

b. Precipitation Intensity

Three regions are depicted by the SPADS analysis (Fig. 49); a region of light to moderate intensity over the extreme north central study area over southern Ontario, a broad region of light to heavy intensity through the east central study area over eastern and southeastern North Carolina and adjacent coastal waters and a region of light to heavy intensity over the southwest quadrant over western and central Florida, southern Georgia and the eastern Gulf of Mexico.

Each area is verified generally well, except the SPADS analysis does not indicate the region depicted by the ARS chart east of the South Carolina and northern Florida coasts. Also, the region depicted by SPADS over the extreme north central region over southern Ontario is noticeably smaller on the ARS chart. The SPADS rainfall rate intensities are overestimated as compared to the surface observed

precipitation intensities. This is probably due to the small area of light precipitation intensity in the SPADS precipitation intensity nomogram (Fig. 6).

4. Cloud-Top Temperature/Height

a. Cloud-Top Temperature

The SPADS analysis of the cloud-top temperature (Fig. 50) is divided into three regions for verification; the central eastern U.S., a region approximately 300 n mi east of the Florida/Georgia coastline and the northern quadrants over the north central U.S.

In the first region, the SPADS analysis is quite reasonable with a range of cloud-top temperatures of 300K to 225K. Of the 22 upper-air observations available, seven were selected for analysis. Of these seven, four are within the central eastern region. The results from these four soundings with the other verification data are depicted in Table X. The maximum cloud-top temperature variation from the SPADS analysis to the upper-air analysis occurs at Charleston, South Carolina (station 72208-CHS) where there is a 9K difference. A minimum difference of 1K is found at Athens, Georgia (station 72311-AHN).

In the second region (east of the Florida/ Georgia coastline) a cloud-top temperature minimum is depicted by SPADS. This correlates well with the manual satellite analysis where massive amounts of cumulonimbus are analyzed which would yield significantly colder cloud-top temperatures and heights.

In the northern quadrants over the north central U.S., the SPADS analysis indicates temperatures associated with surface values with a small area of 240K temperatures which are indicative of cirrus/cirrostratus. There was no independent upper-air observations selected to corroborate this analysis, however, the surface observations and manual satellite analysis indicates the region to be under clear skies or thin cirrus. The analysis by SPADS is noteworthy in this area.

b. Cloud-Top Height

The same areas discussed for the SPADs cloud-top temperature analysis will also be utilized for the SPADS cloud-top height analysis (Fig. 51) discussion.

In the central eastern U.S., the upper-air observation verification data, Table X, indicates a maximum deviation of 70 mb from the SPADS analysis which occurs at Charleston, South Carolina. A minimum of 19 mb occurs at Athens, Georgia. The surface observation reports of cloud bases are inconclusive as predominately overcast low and middle cloud bases are reported. The ARS chart yields a 40,000 ft report to the northeast and a 26,000 ft report to the southwest of Charleston which is indicative of the SPADS analysis of a high cloud-top of 420 mb, approximately 24,000 ft.

In the region approximately 300 n mi east of the Florida/Georgia coastline, the SPADS analysis of cloud-top

heights agree with the cloud heights inferred from the cloud type (cumulonimbus) analyzed by the manual satellite analysis.

In the northern quadrants over the north central U.S., the SPADS analysis depicts height values associated with the surface. The surface observations and ARS chart and the manual satellite analysis confirms the region to be clear or scattered with thin high clouds. In the extreme north central portion of the northern quadrants, the SPADS cloud-top height analysis indicates a range of heights from 500 mb to 200 mb. The manual satellite analysis and surface observations confirm the SPADS analysis.

The SPADS analysis of the cloud-top temperatures/heights are certainly within tolerance levels. Agreement is completely satisfactory, particularly, in the areas where cumulonimbus is confirmed.

V. SUMMARY

Automated cloud and precipitation intensity analysis programs based on satellite imagery are a new innovation. This thesis utilized a program established exclusively for the SPADS which was tested for five summer season cases. The following sections summarize the thesis successes, problems and recommendations for further research.

A. ANALYSIS SUCCESSES

The SPADS automated cloud and precipitation intensity analysis program produced information on cloud amount, cloud type, cloud-top temperature/height and precipitation intensity within an hour of data receipt. Five case studies were successfully analyzed utilizing as many current specific verification tools as were available. The following SPADS program output successes were observed:

- The cloud amount analysis is skillful. Alignment and orientation are excellent.
- The cloud type analysis is skillful but can be improved. Classification of cumuliform cloud types is successful, particularly for cumulonimbus.
- The cloud-top temperature/height analysis is excellent. Realistic temperatures and heights were established in most instances and were consistent with other SPADS generated output. For example, when cumulonimbus were identified, colder temperatures and higher heights were analyzed.
- The precipitation intensity analysis is fair. Differentiation of intensity levels was difficult to establish. The precipitation intensity analysis provides evidence of potential precipitation areas.

B. ANALYSIS PROBLEMS

The analysis problems are broken down into separate subsections, namely algorithm and hardware. In each subsection, individual problems are identified with potential corrections suggested.

1. Algorithm

- The influence of seasonality on the algorithm is obvious. Corrections to the cloud brightness counts were required in order to establish correct cloud amounts. Adjustment of the visual and infrared thresholds for determining cloud types was also required from the studies of Nelson (1982) and Liljas (1981). These corrections were required since the data are from the late summer season and a lower latitude where a higher sun elevation produces more illumination. Continued study of the cloud brightness counts and the visual and infrared digital brightness counts are needed to further improve the cloud amount and cloud type analysis.

- The standard deviation values established by Nelson (1982) were adjusted to improve the discrimination of stratus/fog, stratocumulus/thick fog and cumulus humilis and cirrus/cirrostratus or altostratus. These values require further study to resolve the stratiform versus cumuliform and stratiform versus cirriform situations.

- Regions of thin cirrus are not recognized by the SPADS cloud type algorithm.

- The cloud-top temperature/height analysis produces inordinately high and low values in clear and convective situations. A simple solution is to establish boundary limits for the surface and upper atmosphere. Further study should be directed to understand the problem.

- The cloud type decision process (summation of like cloud types) is unsatisfactory in that the priority system employed may not be sufficient for all types of operational needs and the output only depicts the most numerous cloud type, eliminating all others.

- The evidence of nimbostratus/multi-layered clouds in the SPADS output is generally too extensive. Additional modification of the visual threshold should be investigated.

- Precipitation intensity is difficult to model. The precipitation intensity thresholds from the SPADS analysis need adjustment and probably should indicate a bi-modal (precipitation/no precipitation) solution.

2. Hardware

- The general SPADS display graphics system is inadequate for proper analysis of these sub-synoptic detailed fields. Currently the maximum and minimum values are overlaid on the contoured fields eradicating definition of subtle features. Displayed contours must be re-contoured at proper intervals to generate usable information.

- Data array output must be manipulated to a 64 x 64 array for display.

- The Versatec printer attached to the SPADS display system is inadequate for satellite image output, even though a controllable grey shade scale is available.

C. RECOMMENDATIONS

The cloud and precipitation intensity analysis requires further research. The following recommendations are suggested:

- Use of an albedo algorithm vice brightness counts will eliminate the seasonality influence.

- Further verification testing should be undertaken to evaluate the use of albedo levels and, when operationally established, field tests should be initiated to acquire a user critique.

- A graphics program should be attached to the cloud and precipitation intensity program so that smooth, useful and uncluttered contours could be displayed on the SPADS display system. The cloud amount, cloud-top temperature/height and precipitation intensity should be contoured whereas the cloud type should be color contoured.

- Experiments should commence on night infrared-only analysis with the addition of surface data into the analysis algorithm.

Satellite imagery are currently underutilized. When the cloud and precipitation intensity analysis program is

operational, user uniformity and familiarity will substantially expand the forecasters repertoire of meteorological tools and produce a better sub-synoptic cloud and precipitation intensity analysis.

APPENDIX A

TABLES

TABLE I

Cloud Type Nomenclature and Standard Deviations
(from Nelson, 1982)

Cloud Type	Code Figure	Cloud Priority	Standard Deviation Value (SIG_i)
Cirrus/Cirrostratus	1	9	$\sigma < 1.5$
Altostratus	2	8	$\sigma > 1.5$
Stratus/Fog	3	7	
Stratocumulus/Thick Fog	4	6	$\sigma < 5.0$
Cumulus humilis	5	5	$\sigma > 5.0$
Cumulus congestus--small	6	4	$\sigma < 20.0$
Cumulus congestus--large	7	3	$\sigma > 20.0$
Nimbostratus/multi-layered	8	2	
Cumulonimbus	9	1	

TABLE II

SPADS Precipitation Intensity Categories
(From Nelson, 1982)

Category		Summation of Visible and Infrared Counts
No rain	(0)	SUM < 184
Light rain	(1)	184 < SUM < 195
Moderate rain	(2)	195 < SUM < 224
Heavy rain	(3)	SUM > 224

TABLE III

Observation Network

Surface Network
(Letter Call Sign and International Five-Digit Identifier)

MIA	72202	RIC	72401	LEB	72611
ORL	72205	DCA	72405	BTV	72617
JAX	72206	PHL	72408	GRR	72635
SAV	72207	ROA	72411	FNT	72637
CHS	72208	CRW	72414	HTL	72638
TPA	72211	CVG	72421	MKE	72640
TLH	72214	LEX	72422	MSN	72641
MCN	72217	CMH	72428	GRB	72645
AGS	72218	EVV	72432		
ATL	72219	IND	72438	SSM	72734
MOB	72223			MQT	72743
MGM	72226	LGA	72503	DLH	72745
BGM	72228	BDL	72508		
MEI	72234	BOS	72509		
		PSB	72512		
HAT	72304	IPT	72514		
RDU	72306	BGM	72515		
ORF	72308	ALB	72518		
CAE	72310	SYR	72519		
GSP	72312	PIT	72520		
CLT	72314	CLE	72524		
GSO	72317	BUF	72528		
CHA	72324	PIA	72532		
TYS	72326	FWA	72533		
BNA	72327	MDW	72534		
MEM	72334	DTW	72537		
		DBQ	72547		

Upper-Air Network
(Letter Call Sign and International Five-Digit Identifier)

PBI	72203	WAL	72402	FNT	72637
CHS	72208	IAD	72403	GRB	72645
TBW	72210	HTS	72425	SSM	72734
AYS	72213	DAY	72429		
AQQ	72220	SLO	72433		
CKL	72229				
		ALB	72518		
HAT	72304	PIT	72520		
AHN	72311	BUF	72528		
GSO	72317	PIA	72532		
BNA	72327				

TABLE IV

D/VIP Levels, Categories of Intensities and Rainfall Rates (From FMH-7, Weather Radar Observations, 1982)

D/VIP Level	Echo Intensity	Precip Intensity	Rainfall Rate (in/hr) Stratiform	Convective
1	Weak	Light	< 0.1	< 0.2
2	Moderate	Moderate	0.1-0.5	0.2-1.1
3	Strong	Heavy	0.5-1.0	1.1-2.2
4	Very Strong	Very Heavy		2.2-4.5
5	Intense	Intense		4.5-7.1
6	Extreme	Extreme		> 7.1

TABLE V

Adjusted SPADS Precipitation Intensity Categories

Category		Summation of Visual and Infrared Counts
No rain	(0)	SUM < 194
Light rain	(1)	194 < SUM < 205
Moderate rain	(2)	205 < SUM < 250
Heavy rain	(3)	SUM > 250

TABLE VI

Cloud-Top Heights/Temperatures Derived from Upper-Air Soundings for 02 AUG 83

Station Number	Upper-air analysis tops(mbs):temps(K)	Sfc obs base(ft)	ARS chart tops(ft)	Pilot reports base/tops(ft)	SPADS analysis Hgt(mbs):Temp(K)
72229/CKL	985:294 565:269 367:250	3000 BKN 10000 BKN 20000 BKN	N/A	N/A	372:252
72311/AHN	967:291 535:268 300:238	N/A	20000	N/A	350:251
72317/GSO	975:294 640:275 277:233	10000 SCT 25000 OVC	N/A	N/A	385:249
72402/WAL	561:269 335:244	N/A	N/A	N/A	330:250
72518/ALB	700:276	2000 BKN 8000 BKN	N/A	N/A	750:284
72528/BUF	920:298	1900 BKN	N/A	N/A	930:300

TABLE VII

Cloud-Top Heights/Temperatures Derived from Upper-Air Soundings for 11 AUG 83

Station Number	Upper-air analysis tops(mbs):temps(K)	Sfc obs base(ft)	ARS chart tops(ft)	Pilot reports base/tops(ft)	SPADS analysis Hgt(mbs):Temp(K)
72518/ALB	850:285 500:261 318:242	400 SCT 700 BKN 2000 OVC	N/A	#3 b 6000 #4 b 16000	253:244
72520/PIT	700:280 300:240	4000 SCT 9000 OVC	29000	N/A	292:237
72528/BUF	500:263 300:238	N/A	35000	N/A	328:231
72637/FNT	850:289 670:274	500 SCT 1100 OVC	N/A	N/A	700:282
72645/GRB	756:279	1500 OVC	N/A	N/A	690:284

TABLE VIII

Cloud-Top Heights/Temperatures Derived from Upper-Air Soundings for 23 AUG 83

Station Number	Upper-air analysis tops(mbs):temps(K)	Sfc obs base(ft)	ARS chart tops(ft)	Pilot reports base/tops(ft)	SPADS analysis Hgt(mbs):Temp(K)
72304/HAT	522:266 300:242	3000 BKN 10000 OVC	15000	N/A	327:245
72403/IAD	831:289 490:266	2500 SCT 3300 BKN 7000 OVC	N/A	N/A	501:266
72425/HTS	541:267 449:260	N/A	N/A	N/A	570:273
72433/SLO	934:295 557:272	N/A	23000	N/A	420:260
72532/PIA	792:287 500:265	4200 SCT 12000 BKN	25000	N/A	480:266

TABLE IX

Cloud-Top Heights/Temperatures Derived from Upper-Air Soundings for 31 AUG 83

Station Number	Upper-air analysis tops(mbs):temps(K)	Sfc obs base(ft)	ARS chart tops(ft)	Pilot reports base/tops(ft)	SPADS analysis Hgt(mbs):Temp(K)
72311/AHN	940:295 641:276	N/A	N/A	N/A	469:263
72327/BNA	522:268	12000 BKN 25000 BKN	N/A	N/A	460:258
72403/IAD	323:241	5000 SCT 7000 BKN 10000 OVC	N/A	N/A	329:254
72518/ALB	769:280 603:269	1200 SCT 2000 BKN 8000 OVC	24000	N/A	535:262
72520/PIT	500:263	600 SCT 4000 OVC	N/A	N/A	470:262

TABLE X

Cloud-Top Heights/Temperatures Derived from Upper-Air Soundings for 02 SEP 83

Station Number	Upper-air analysis tops(mbs):temps(K)	Sfc obs base(ft)	ARS chart tops(ft)	Pilot reports base/tops(ft)	SPADS analysis Hgt(mbs):Temp(K)
72203/PBI	976:298 700:280 400:257	2000 SCT 6000 SCT 12000 BKN 25000 BKN	40000	N/A	328:250
72208/CHS	850:289 350:248	400 BKN 2000 OVC	40000	N/A	420:257
72210/TBW	824:288 435:260	N/A	N/A	N/A	400:253
72220/AQQ	963:295 400:255	9000 OVC	N/A	N/A	310:240
72304/HAT	671:277 268:233	2500 SCT 9000 OVC	N/A	N/A	298:235
72311/AHN	519:266	N/A	N/A	N/A	500:265
72317/GSO	850:287 300:239	800 BKN 2000 OVC	25000	N/A	370:245

APPENDIX B

FIGURES

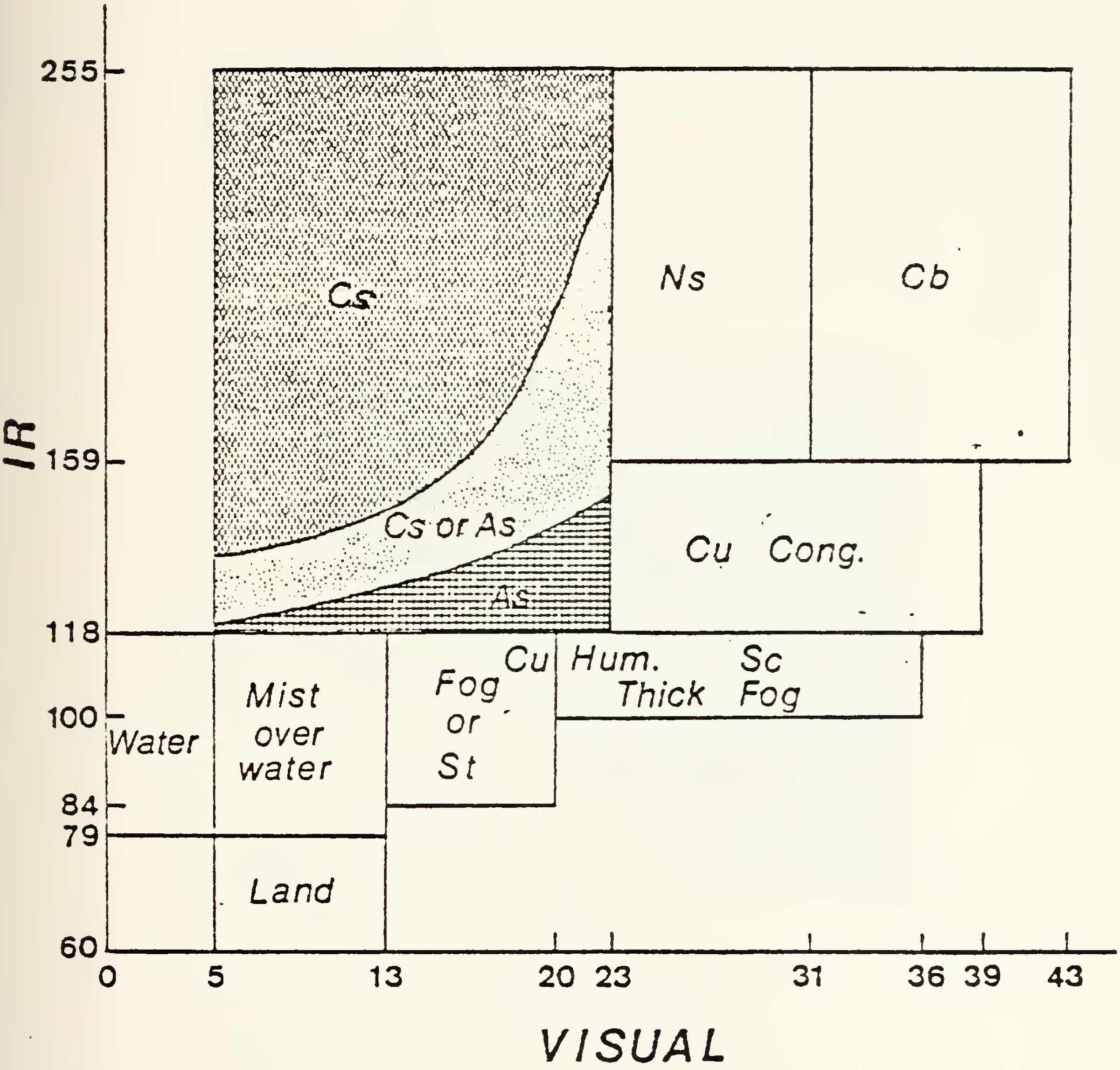

Figure 1. Cloud Threshold (from Nelson, 1982)

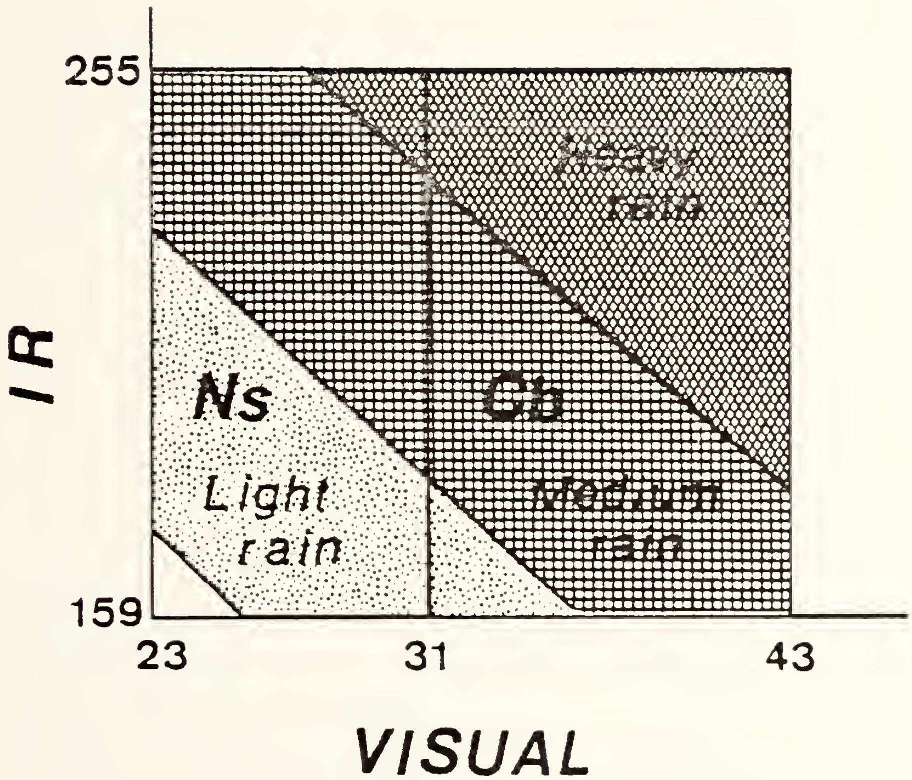

Figure 2. Graph of SPADS Cloud Model Precipitation Intensities

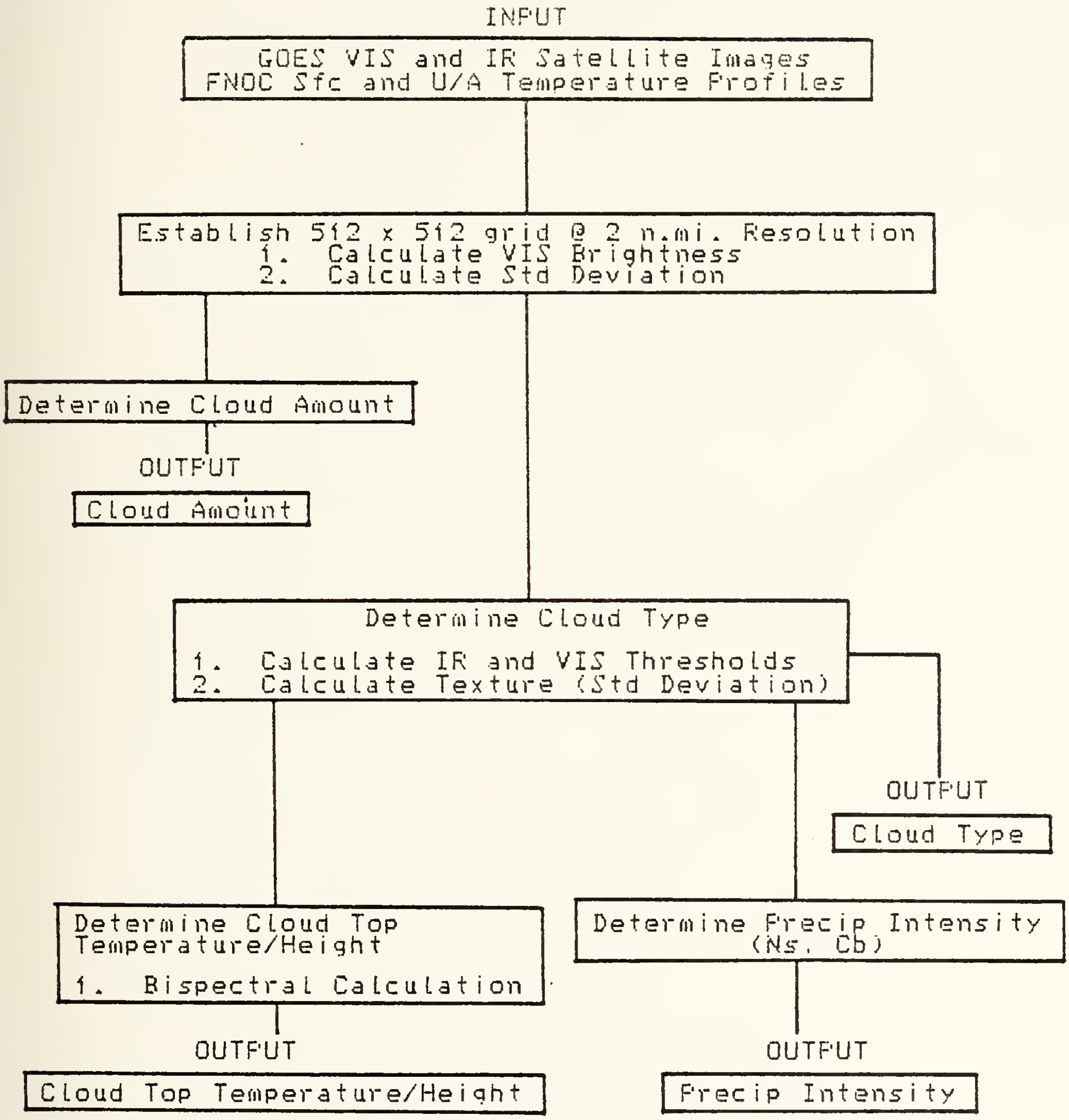

Figure 3. SPADS Flow Chart

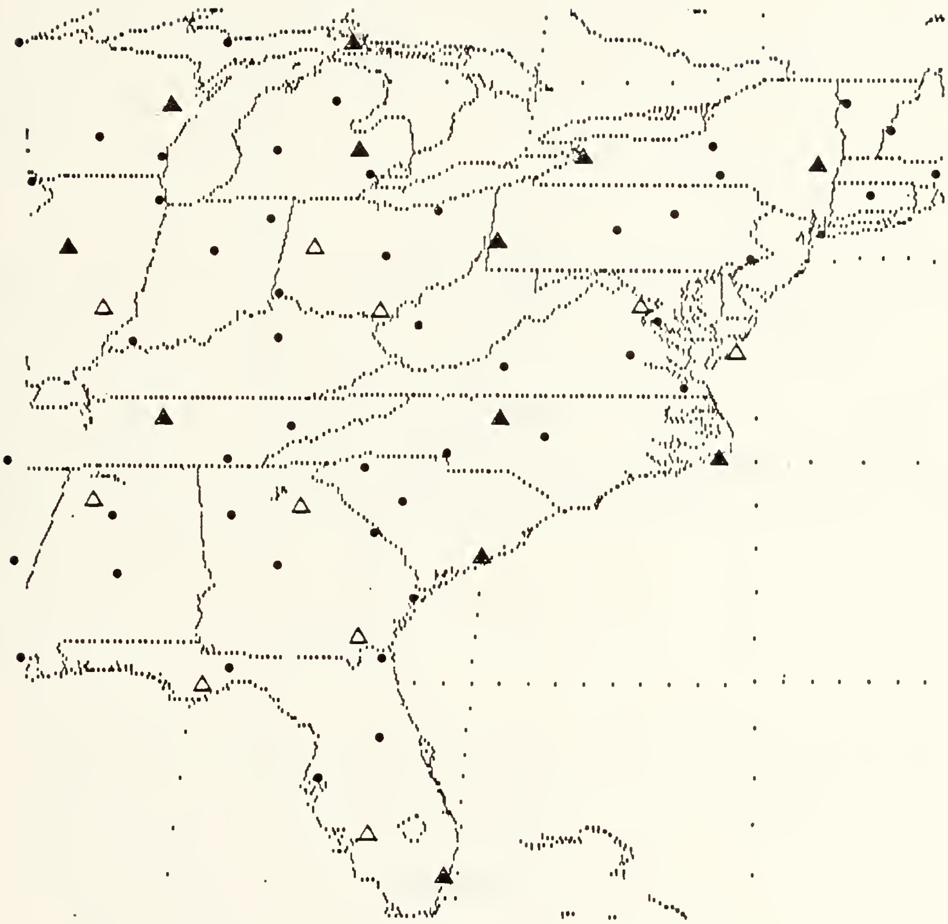

Figure 4. Geographic Location of Study Region
● Surface Observation Verification Network
△ Upper-Air Observation Verification Network

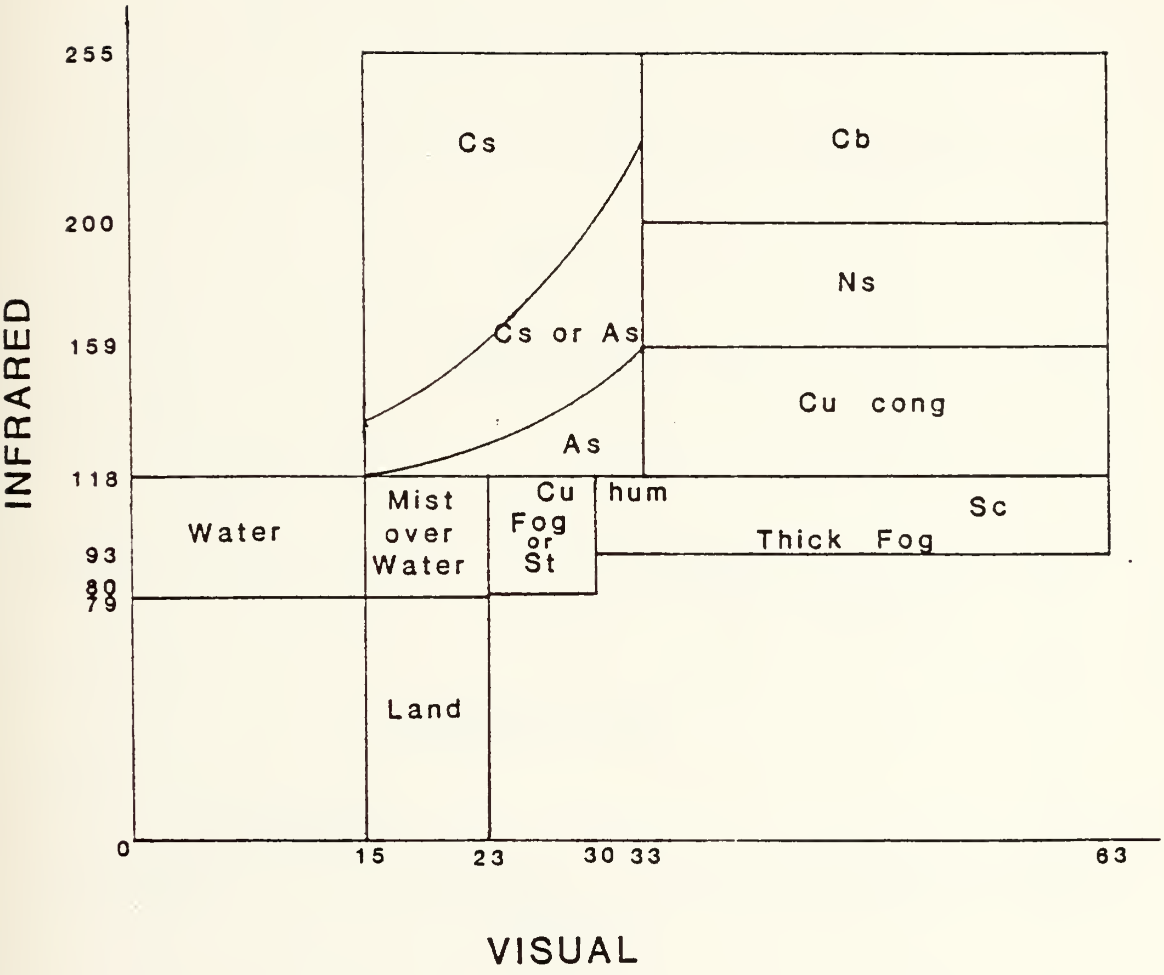

Figure 5. Adjusted Two Dimensional Cloud Typing Nomogram

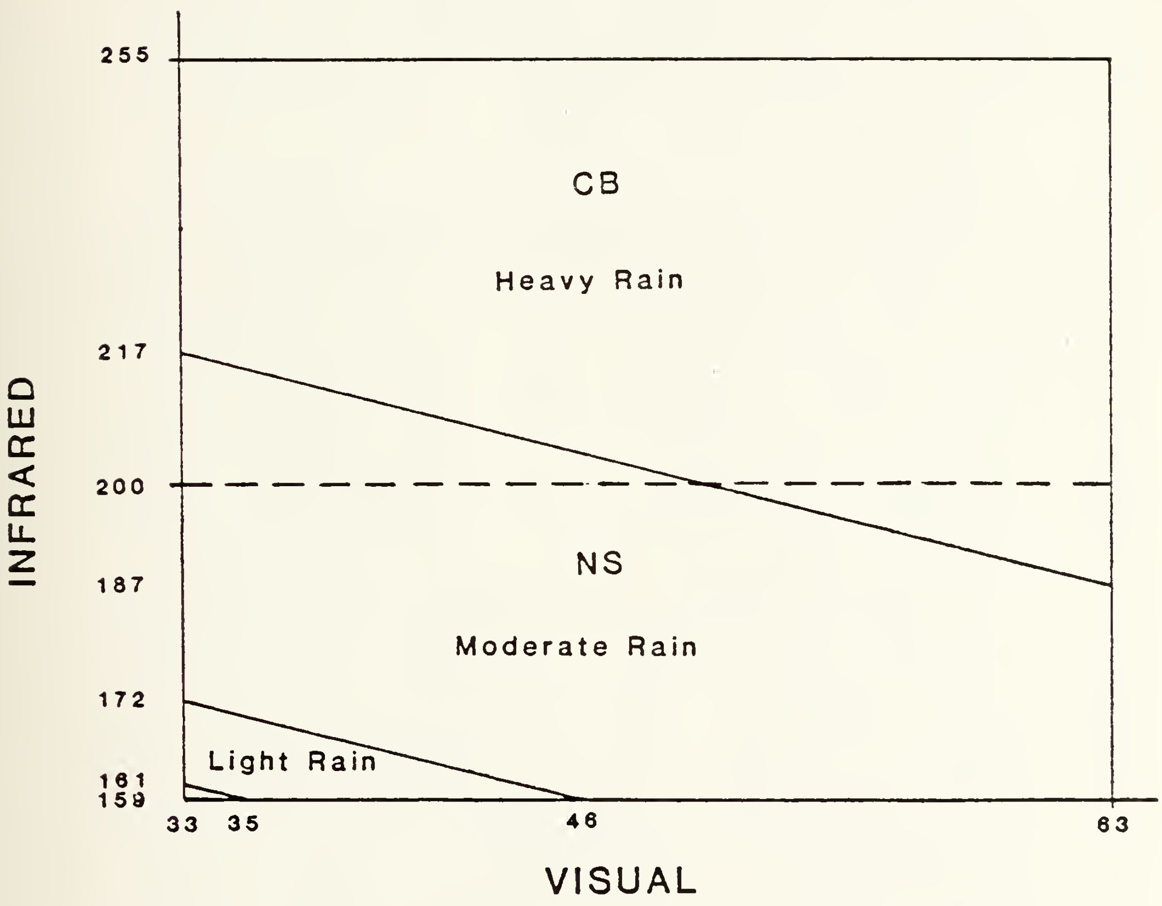

Figure 6. Adjusted Two Dimensional Precipitation Intensity Nomogram

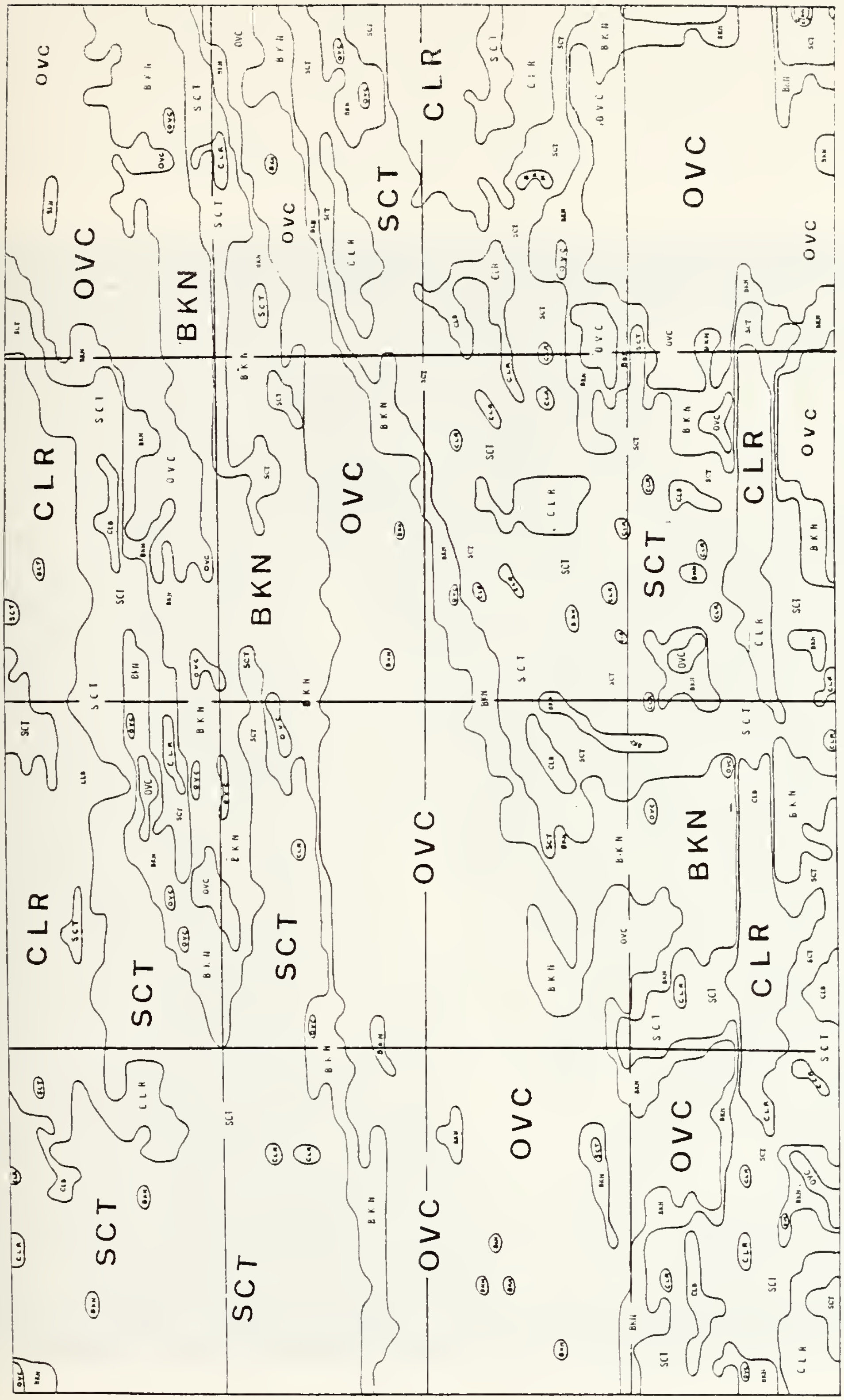

Figure 7. SPADS Contoured Cloud Amount for 02 AUG 83

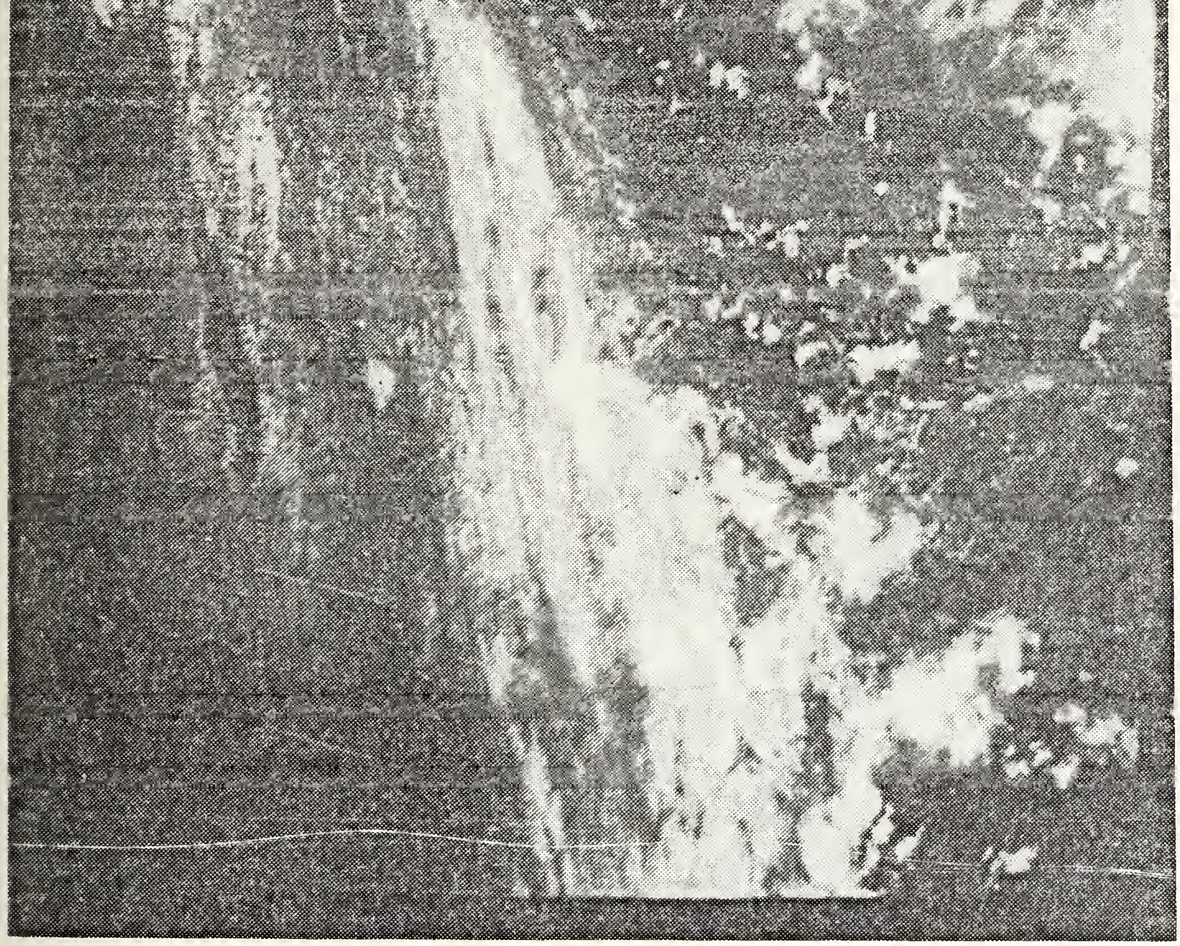

Figure 8. GOES Visual Imagery for 02 AUG 83

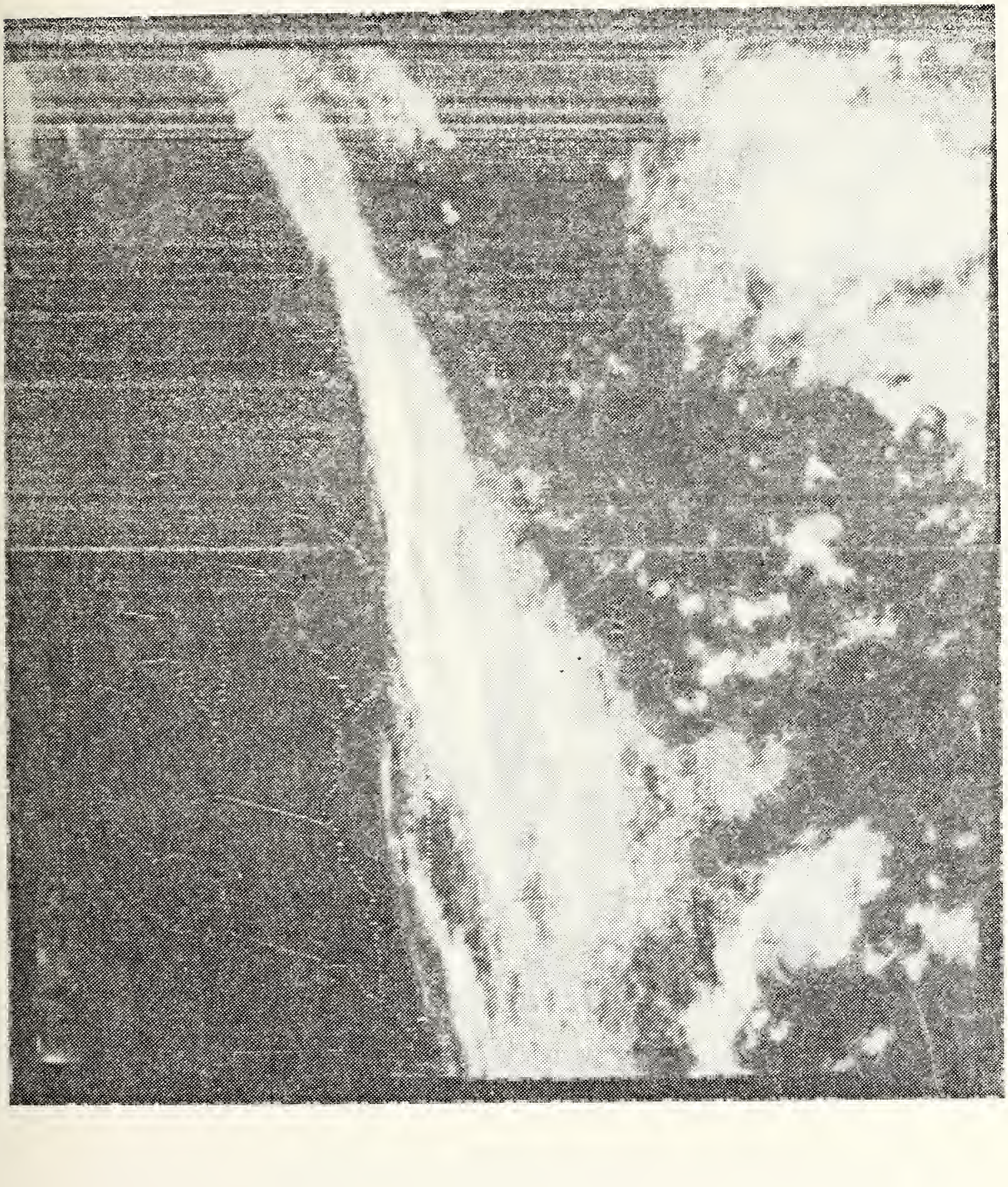

Figure 9. GOES Infrared Imagery for 02 AUG 83

Figure 10. Manual Satellite Analysis Verification Chart for 02 AUG 83

Figure 11. Surface Observation and ARS Verification Chart for 02 AUG 83

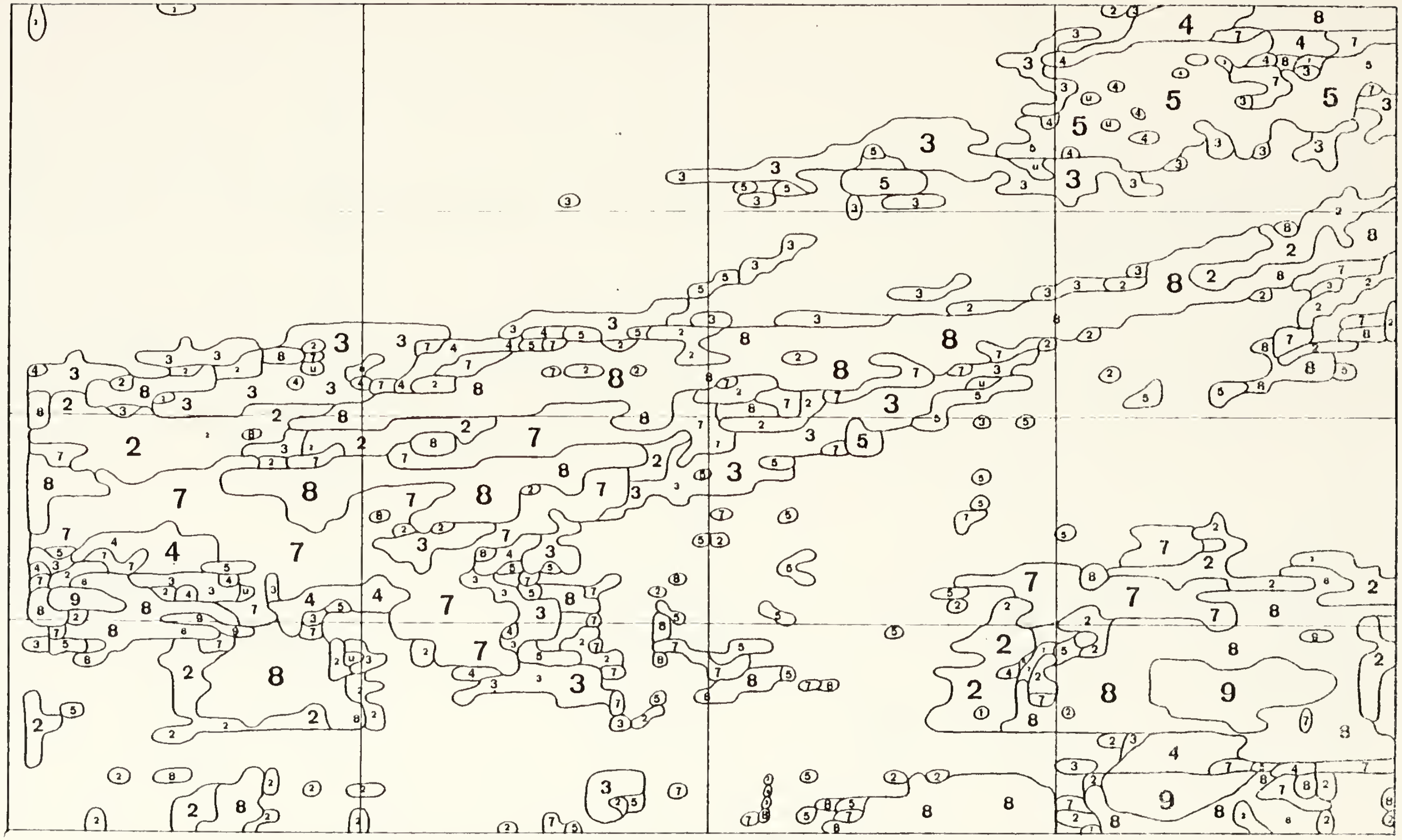

Figure 12. SPADS Contoured Cloud Type for 02 AUG 83

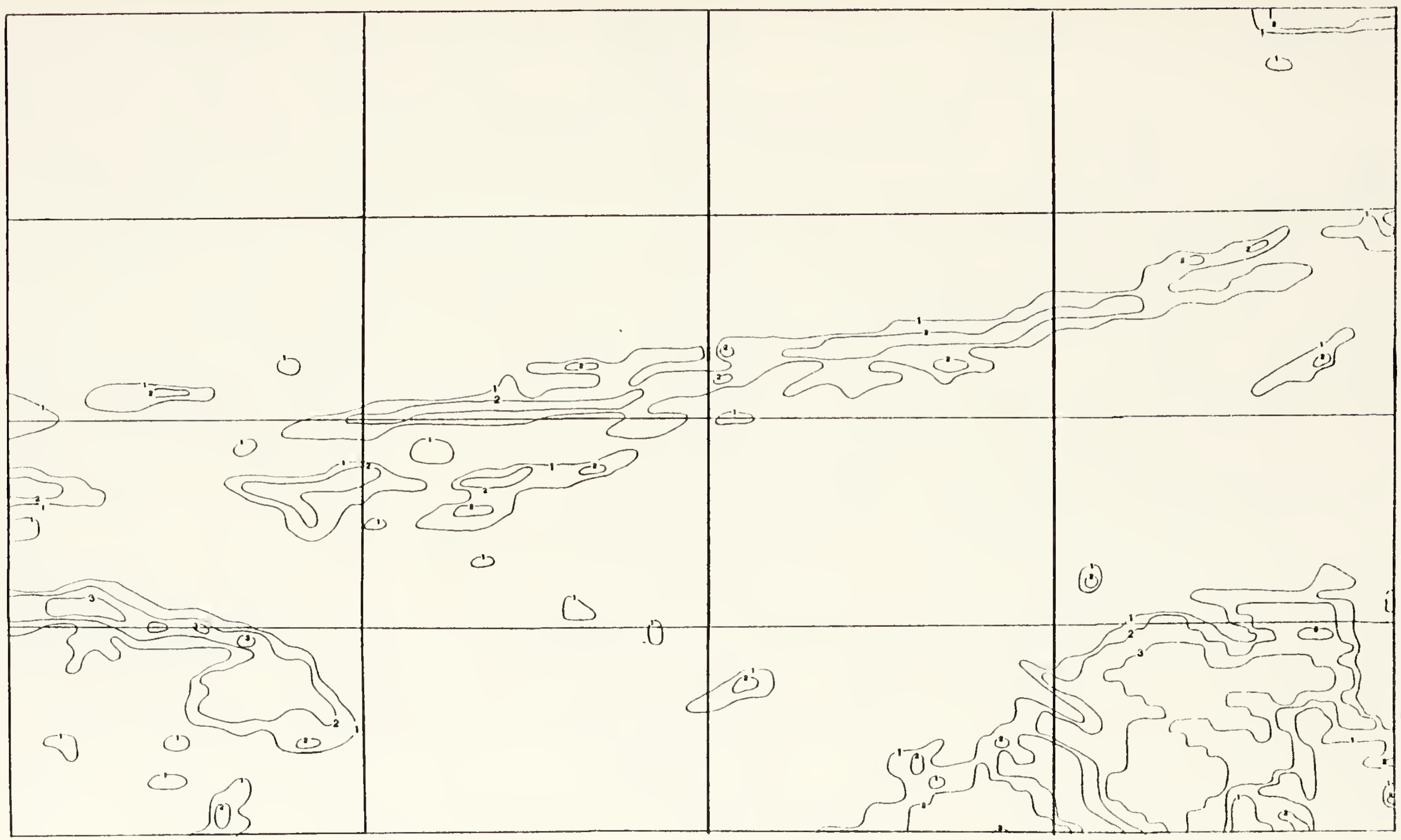

Figure 13. SPADS Contoured Precipitation Intensity for 02 AUG 83

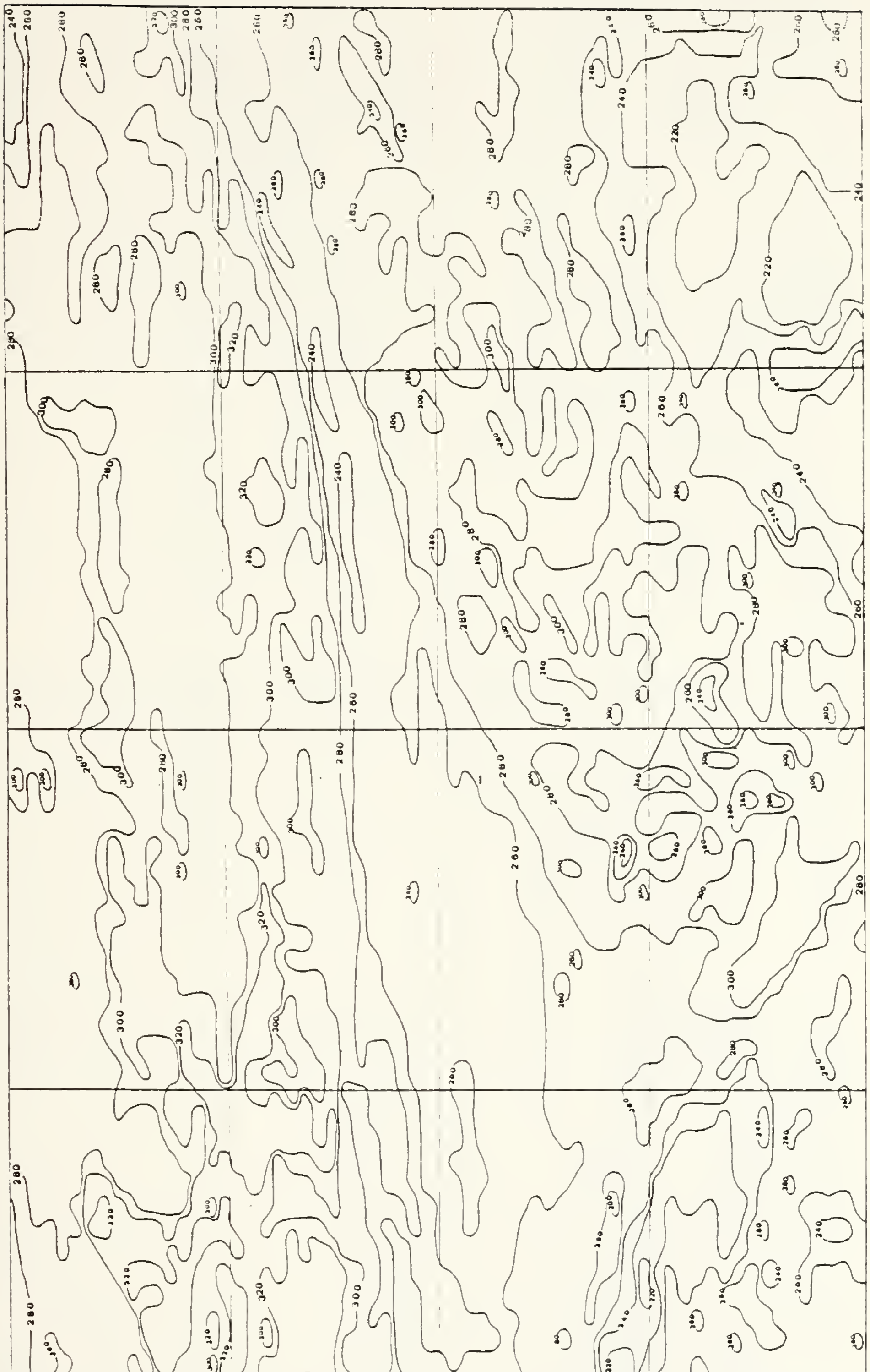

Figure 14. SPADS Contoured Cloud-Top Temperature for 02 AUG 83

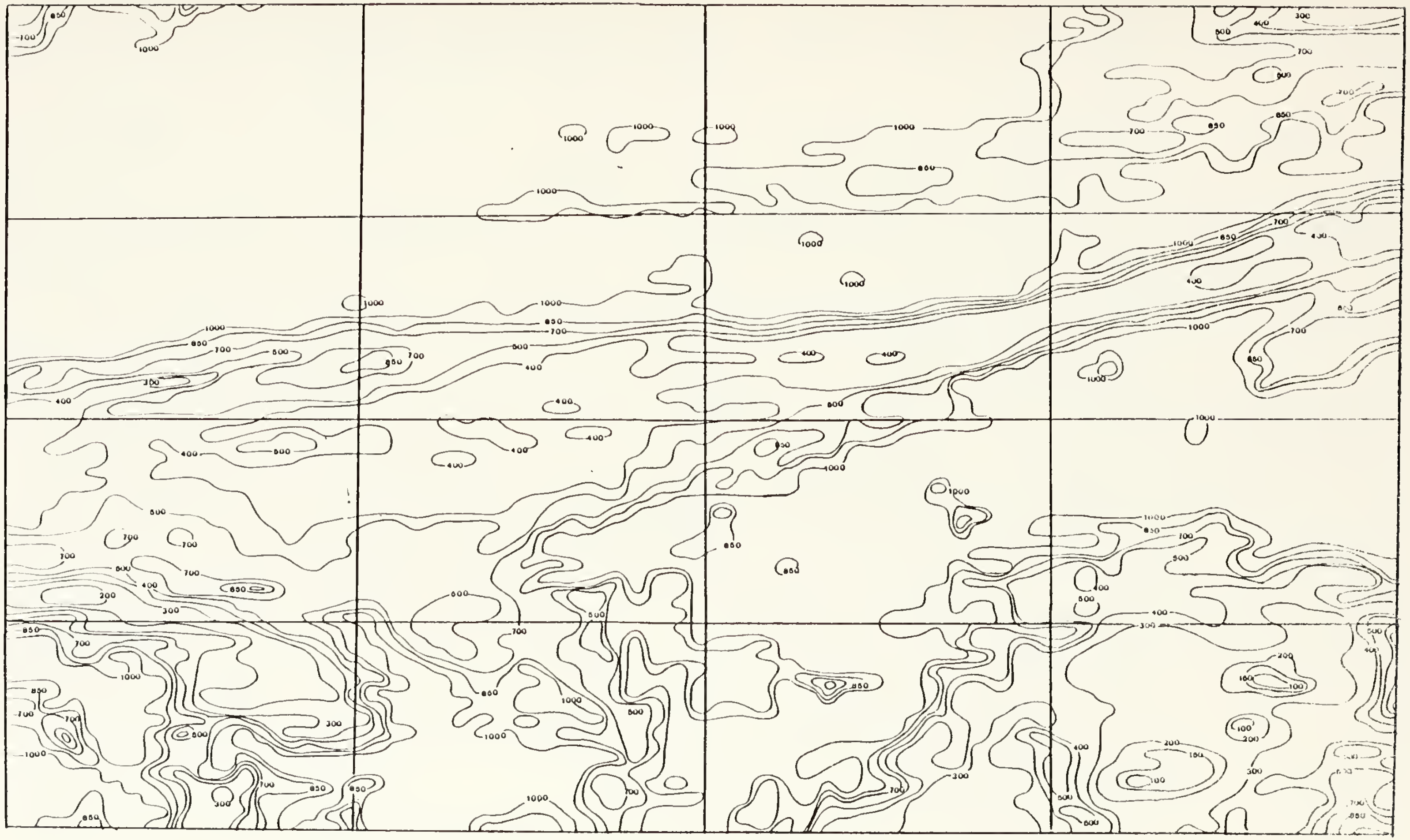

Figure 15. SPADS Contoured Cloud-Top Height for 02 AUG 83

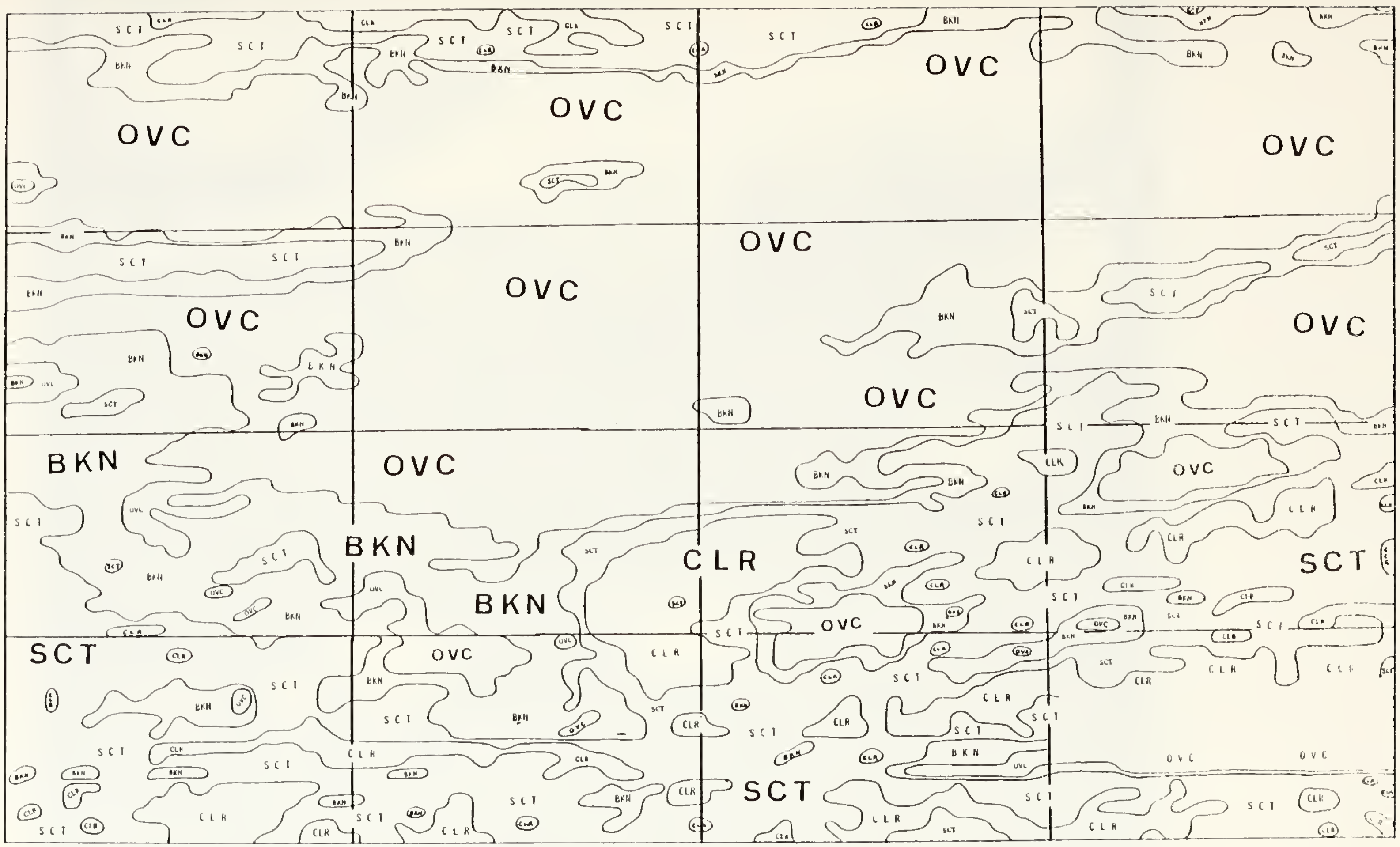

Figure 16. SPADS Contoured Cloud Amount for 11 AUG 83

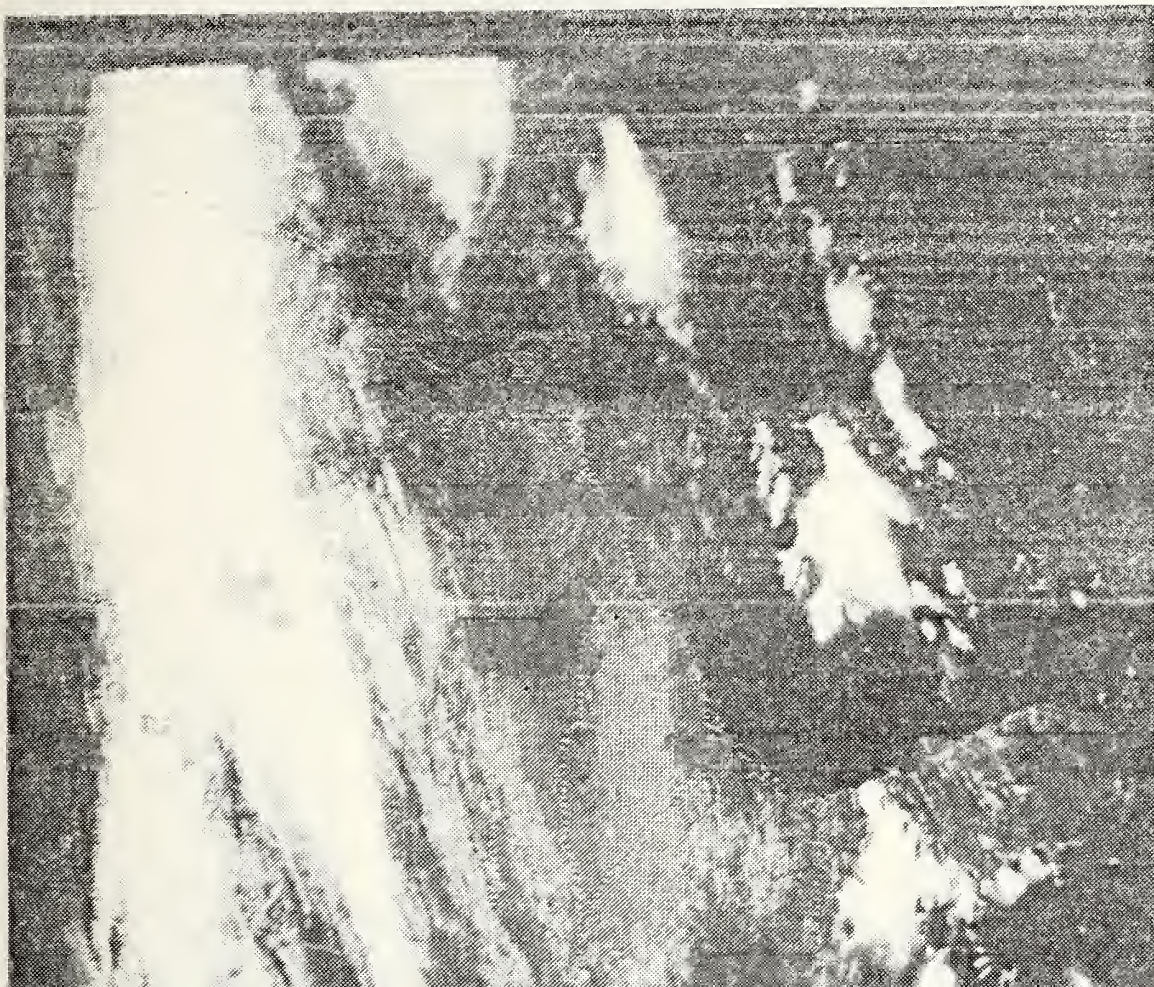

Figure 17. GOES Visual Imagery for 11 AUG 83

Figure 18. GOES Infrared Imagery for 11 AUG 83

Figure 19. Surface Observation and ARS Verification Chart for 11 AUG 83

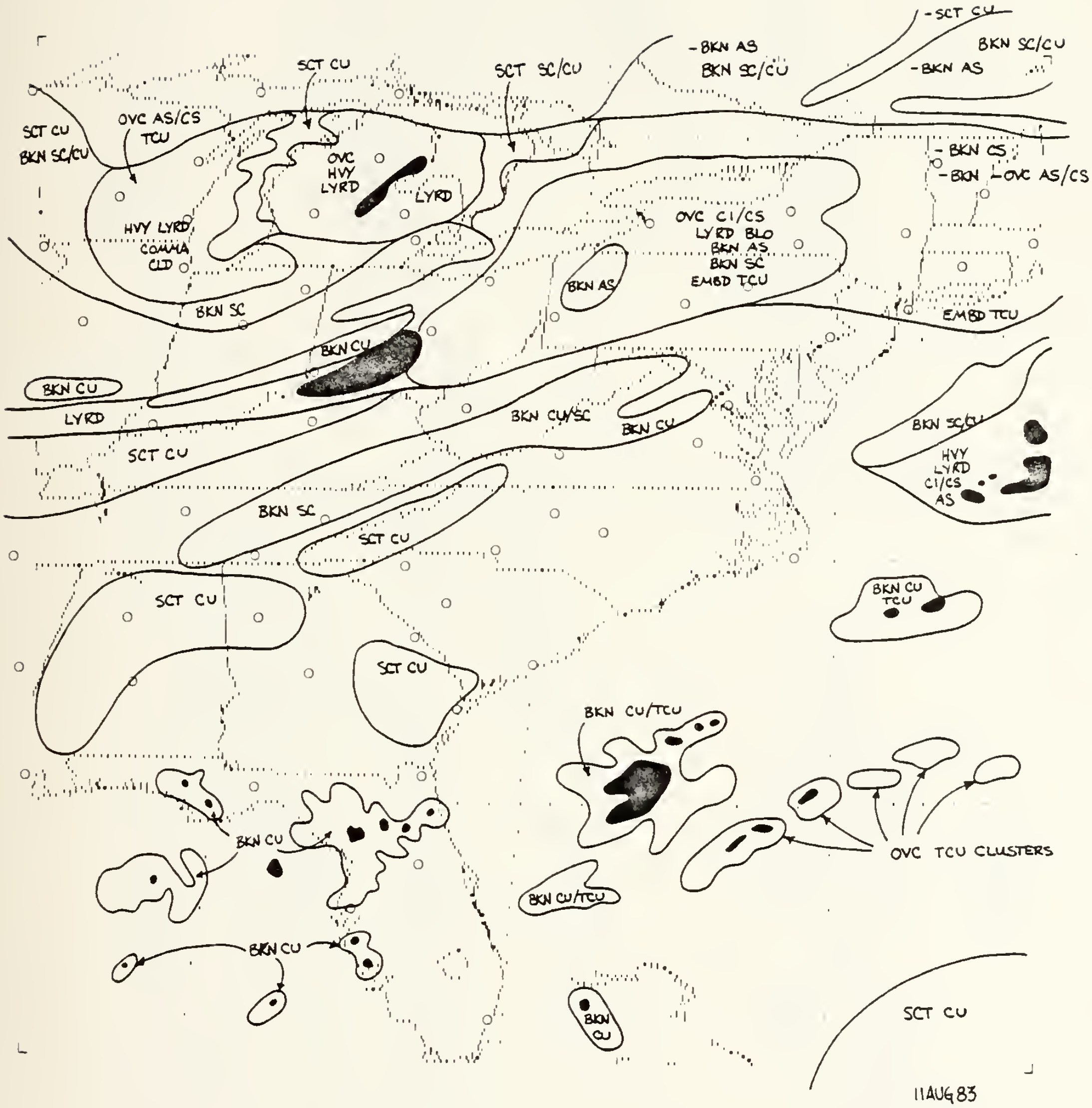

Figure 20. Manual Satellite Analysis Verification Chart for 11 AUG 83

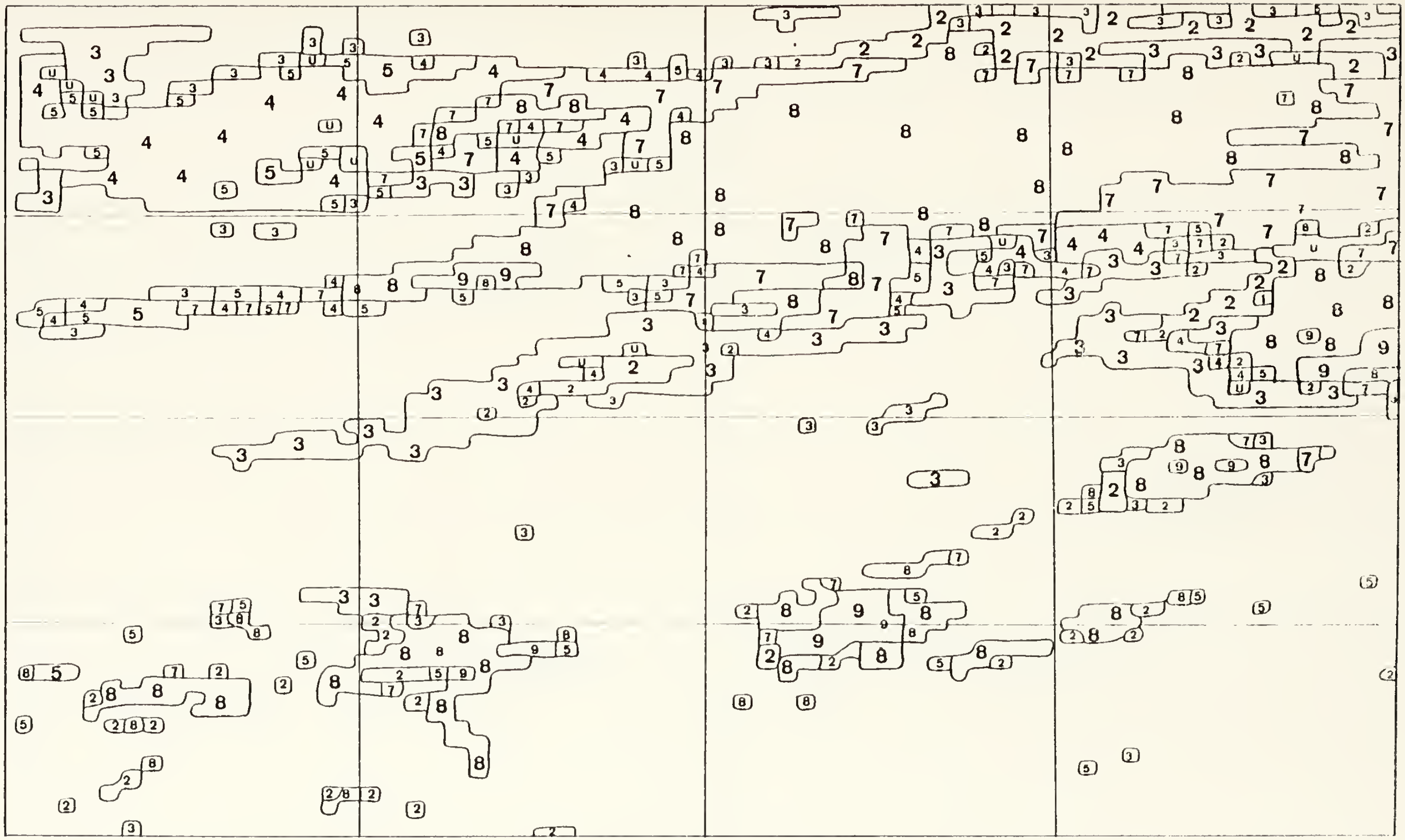

Figure 21. SPADS Contoured Cloud Type for 11 AUG 83

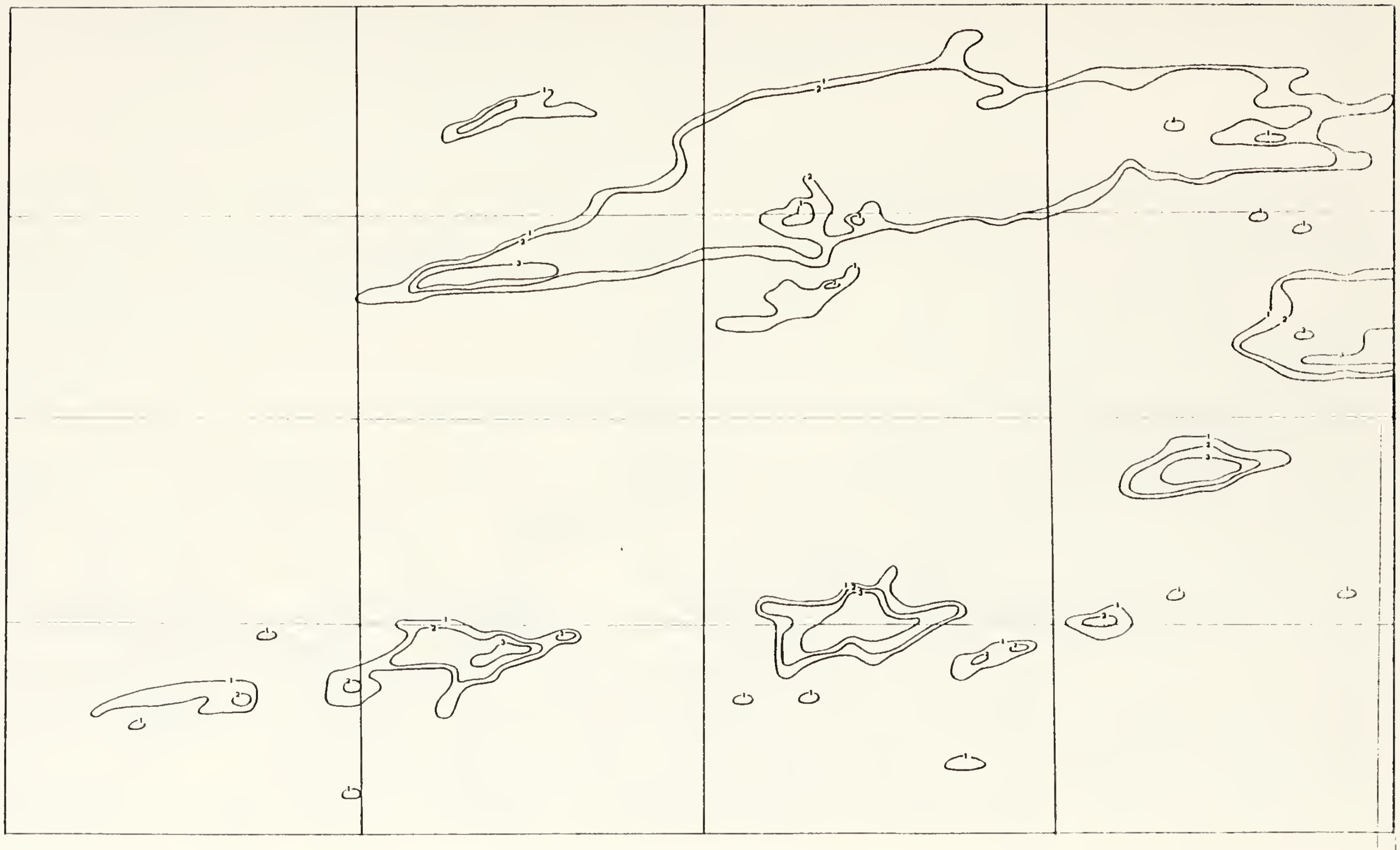

Figure 22. SPADS Contoured Precipitation Intensity for 11 AUG 83

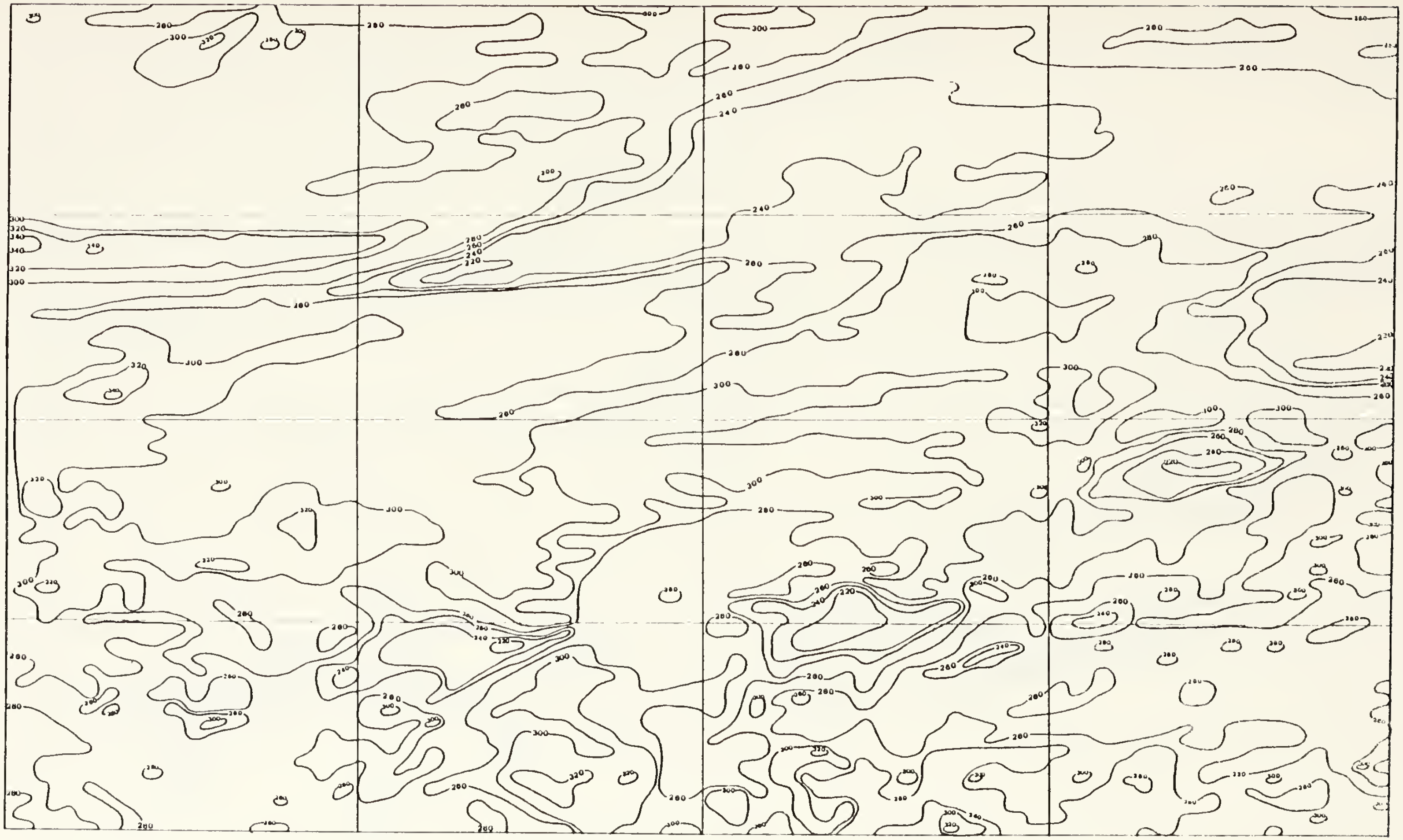

Figure 23. SPADS Contoured Cloud-Top Temperature for 11 AUG 83

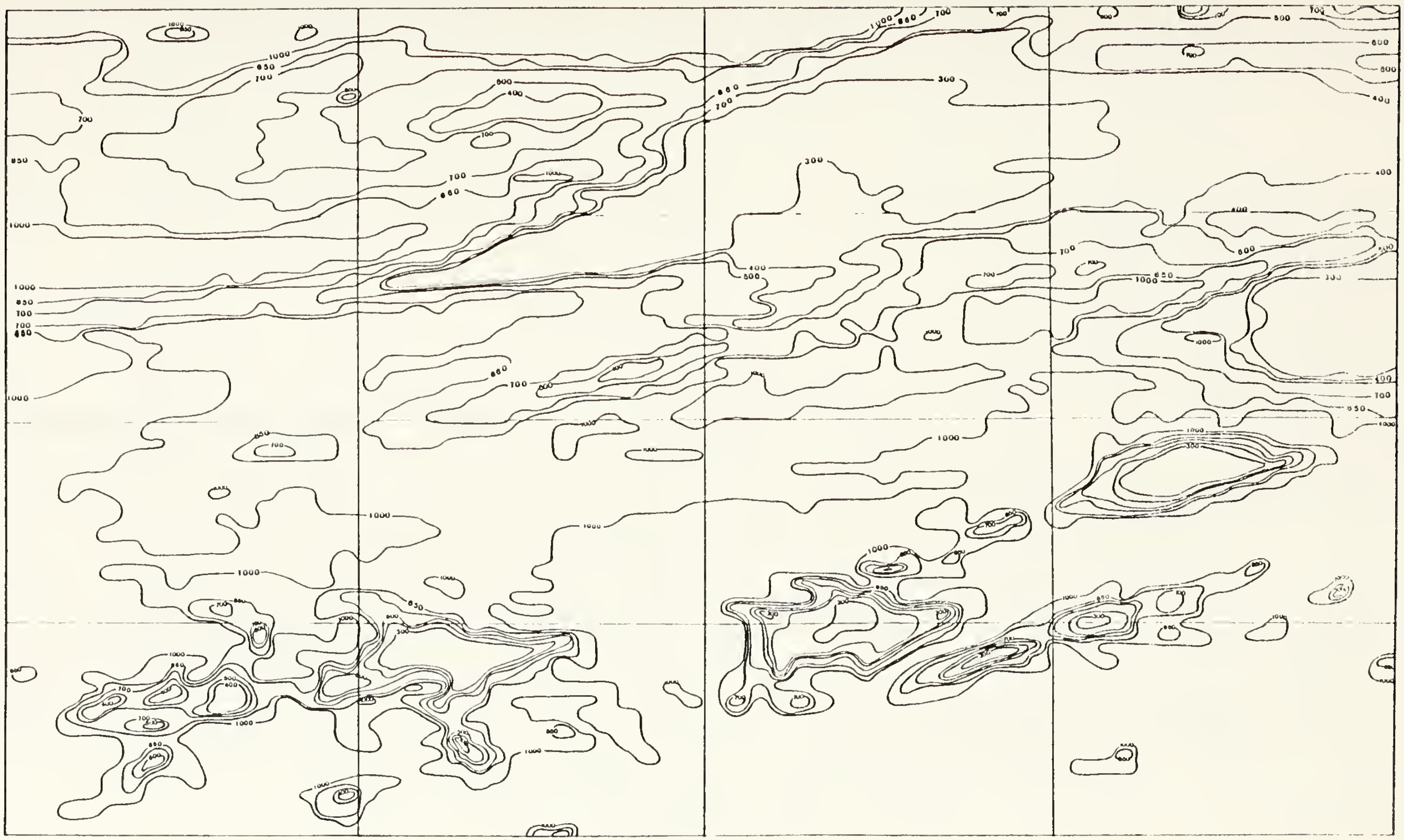

Figure 24. SPADS Contoured Cloud-Top Height for 11 AUG 83

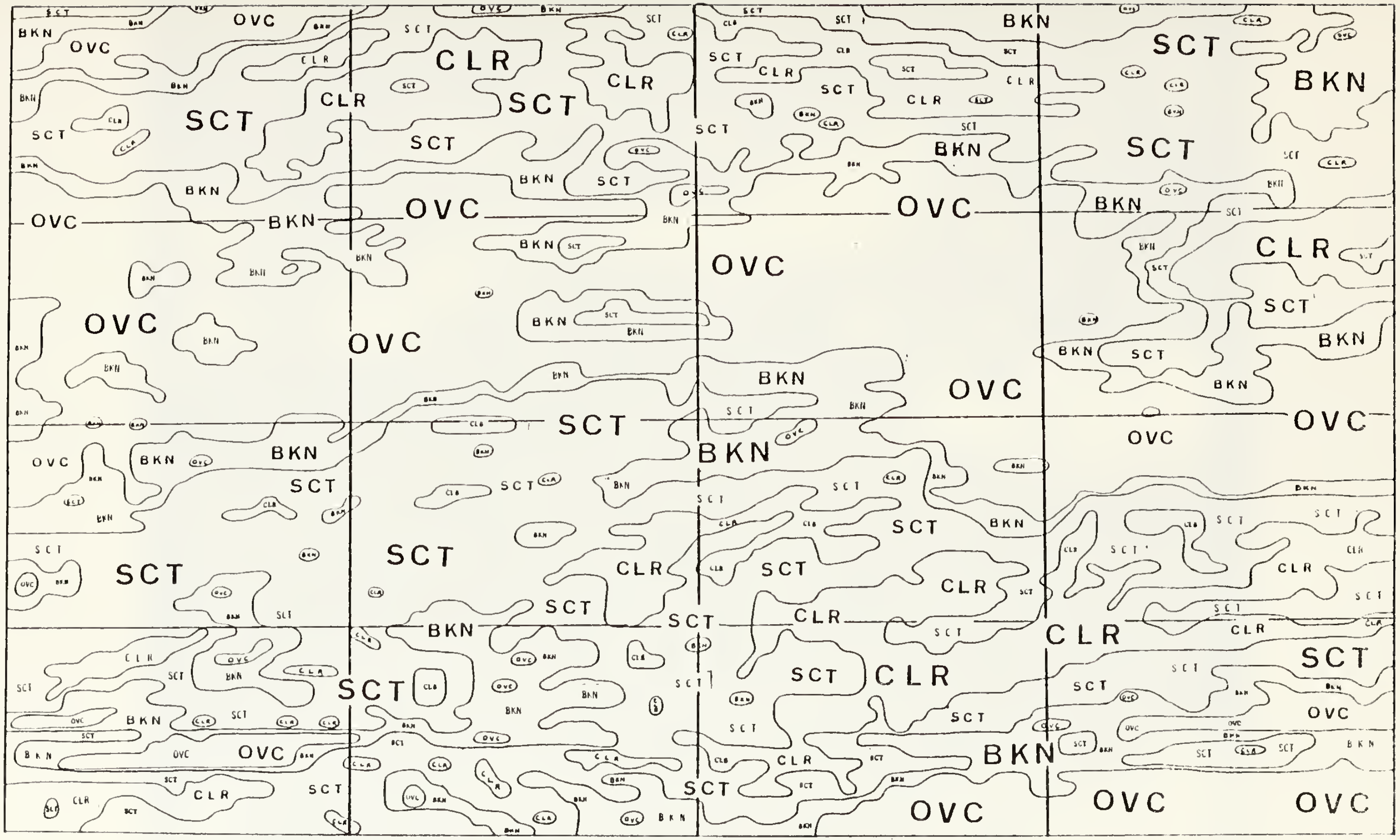

Figure 25. SPADS Contoured Cloud Amount for 23 AUG 83

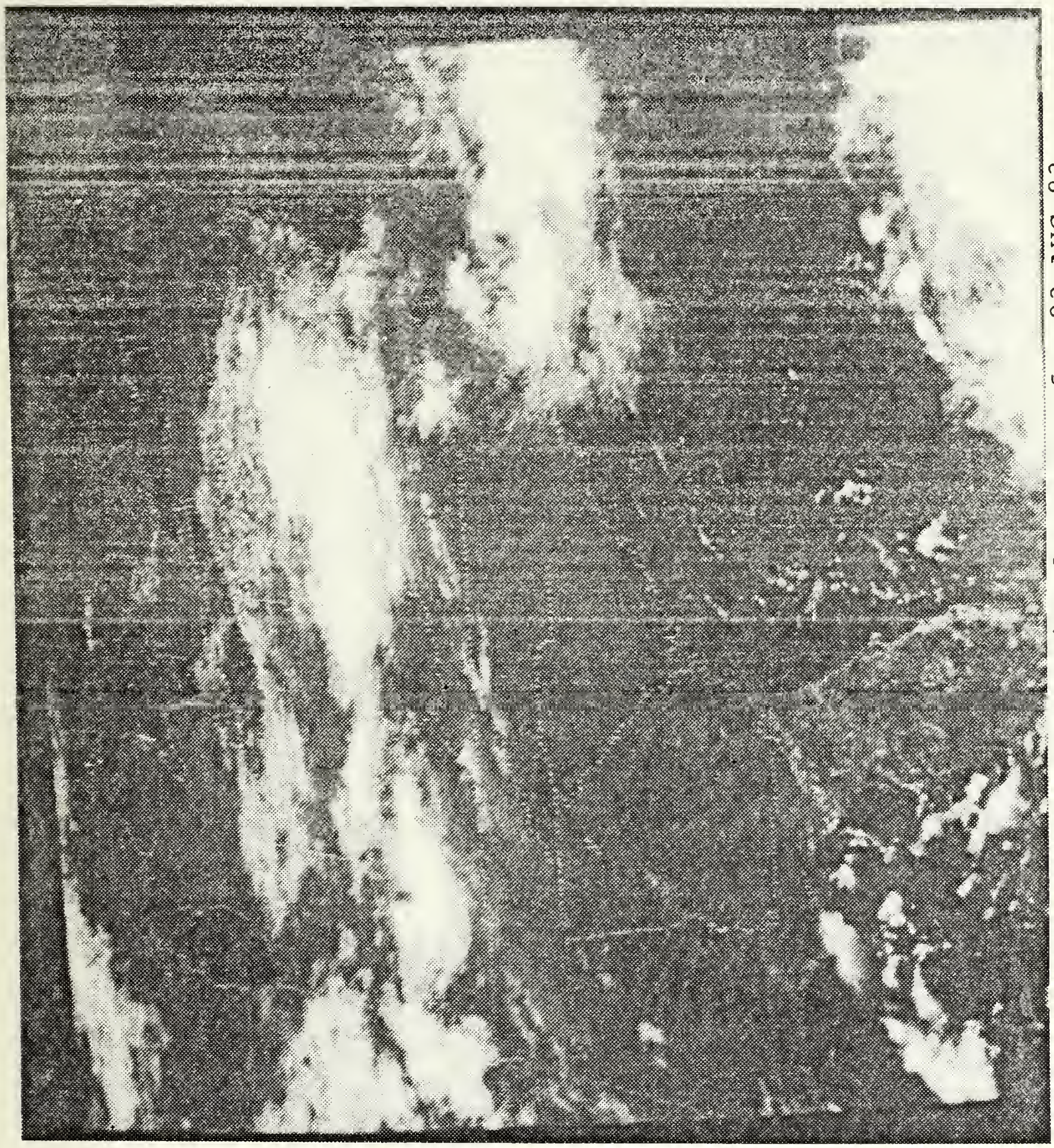

Figure 26. GOES Visual Imagery for 23 AUG 83

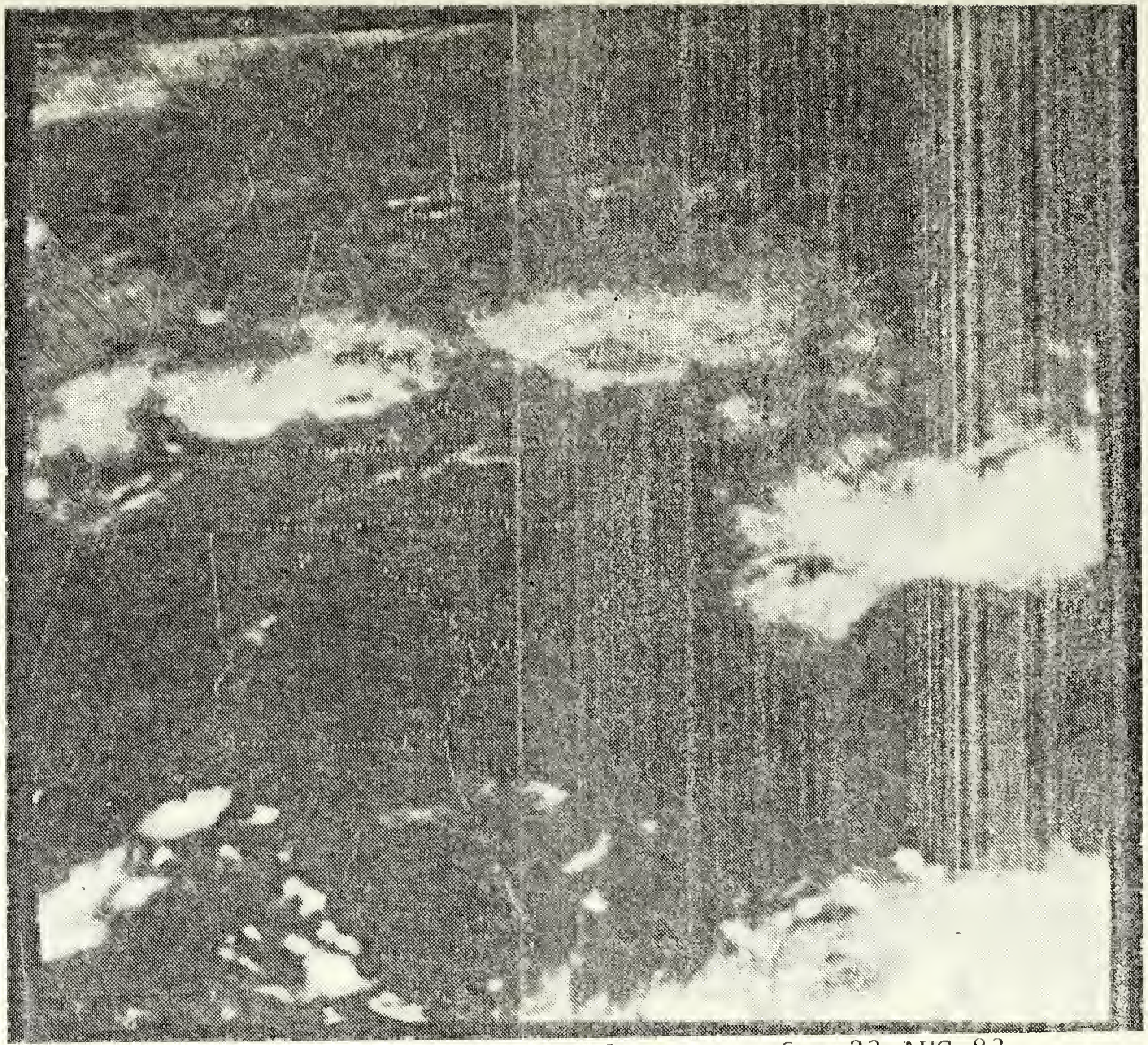

Figure 27. GOES Infrared Imagery for 23 AUG 83

Figure 28. Manual Satellite Analysis Verification Chart for 23 AUG 83

Figure 29. Surface Observation and ARS Verification Chart for 23 AUG 83

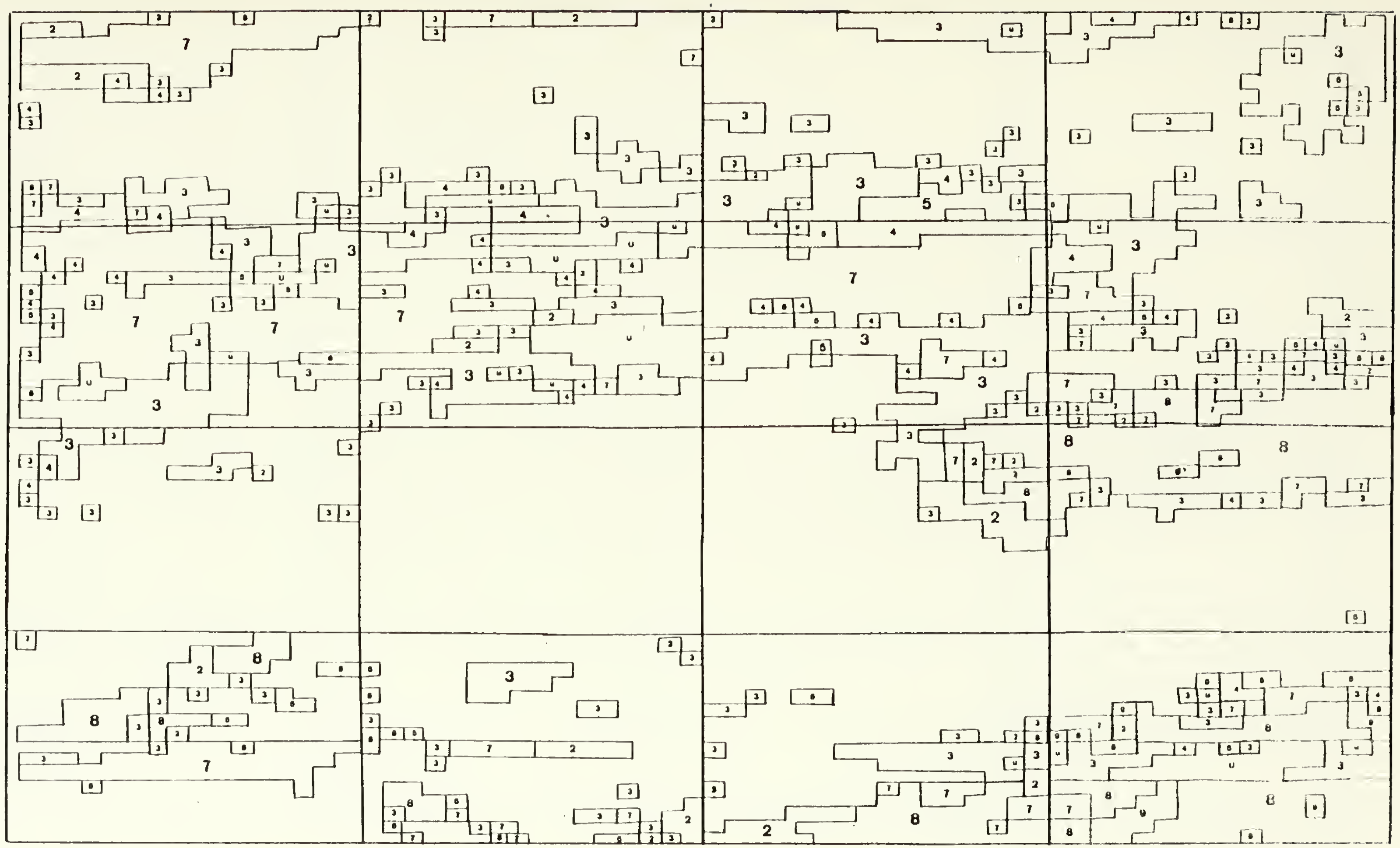

Figure 30. SPADS Contoured Cloud Type for 23 AUG 83

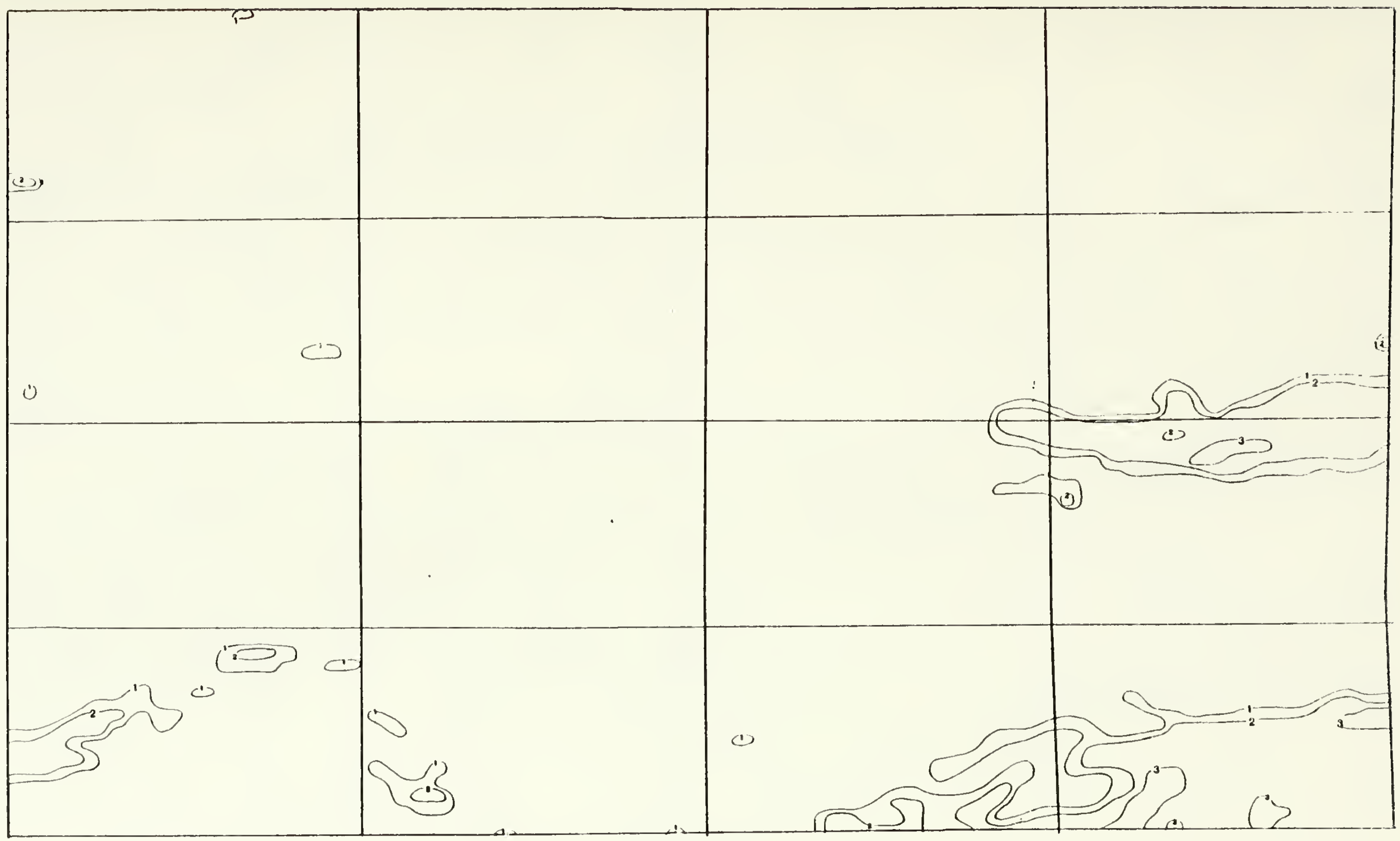

Figure 31. SPADS Contoured Precipitation Intensity for 23 AUG 83

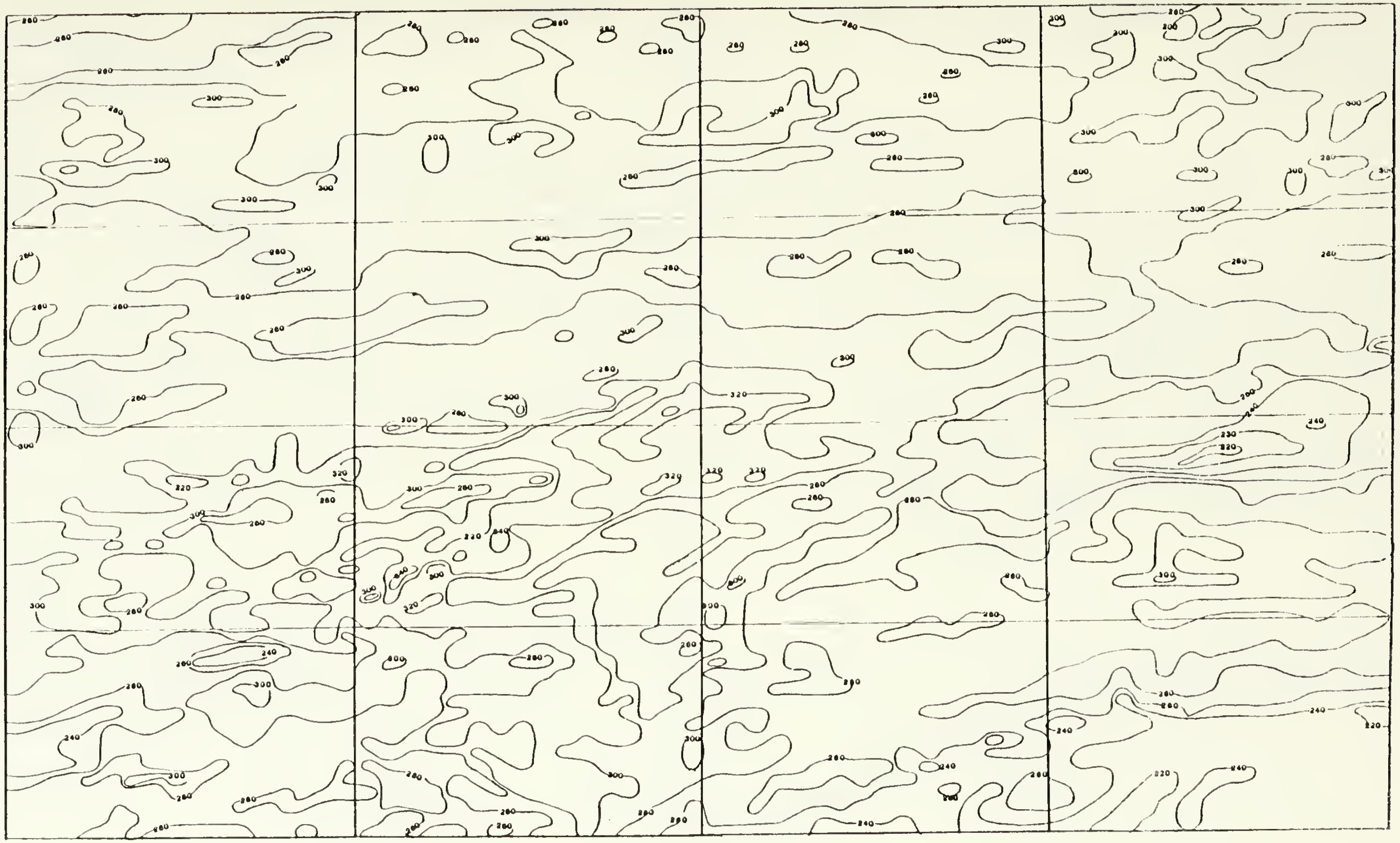

Figure 32. SPADS Contoured Cloud-Top Temperature for 23 AUG 83

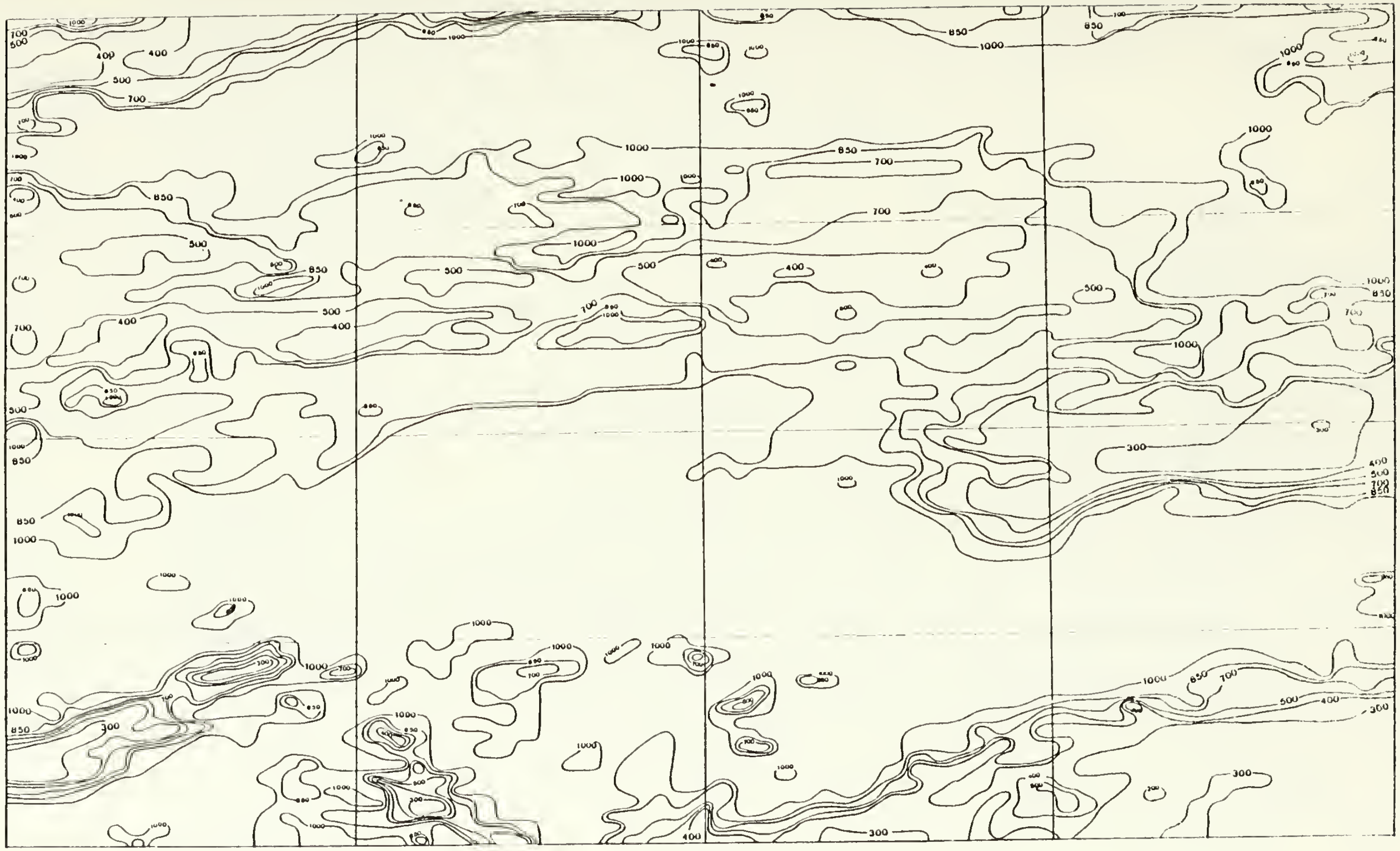

Figure 33. SPADS Contoured Cloud-Top Height for 23 AUG 83

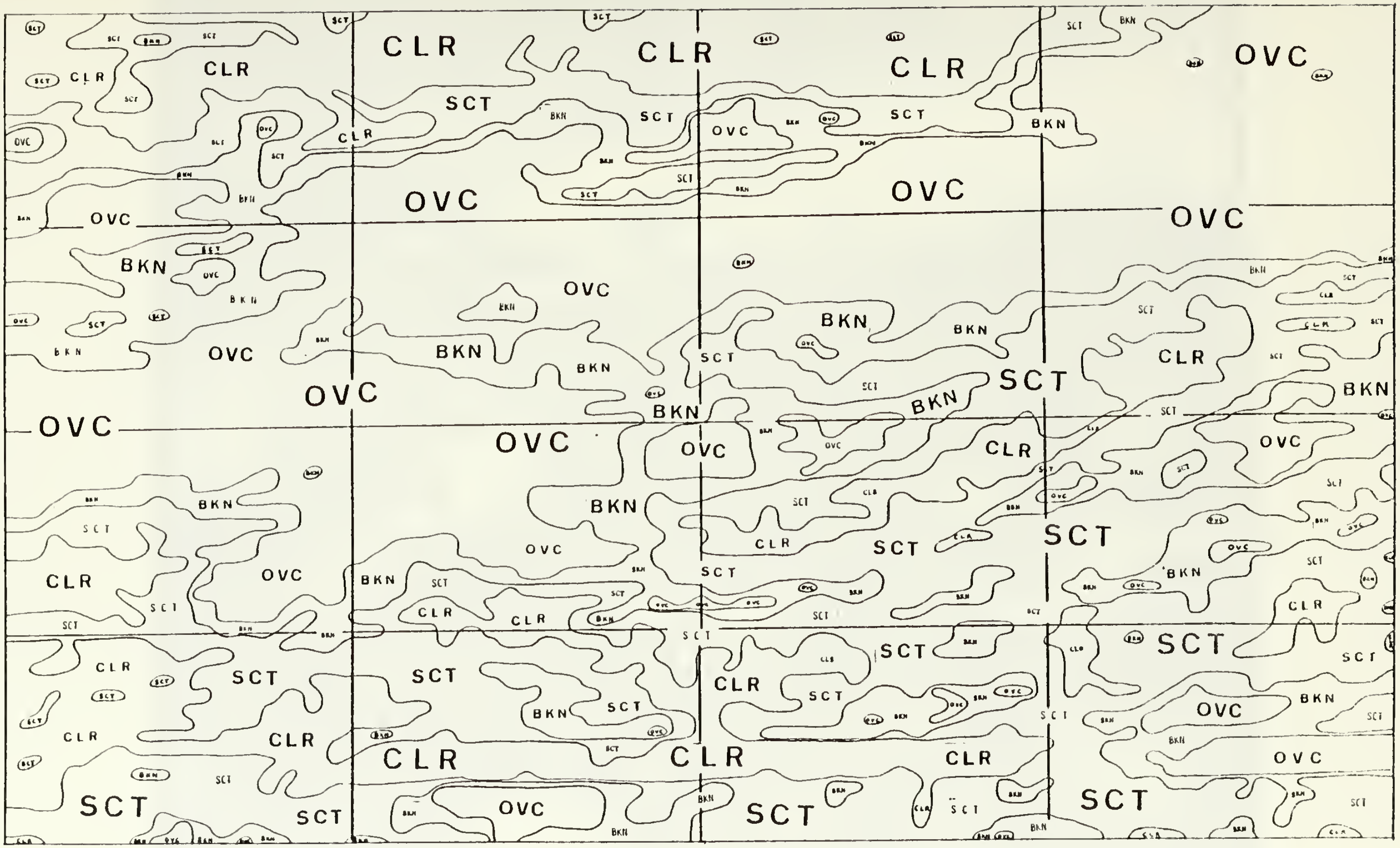

Figure 34. SPADS Contoured Cloud Amount for 31 AUG 83

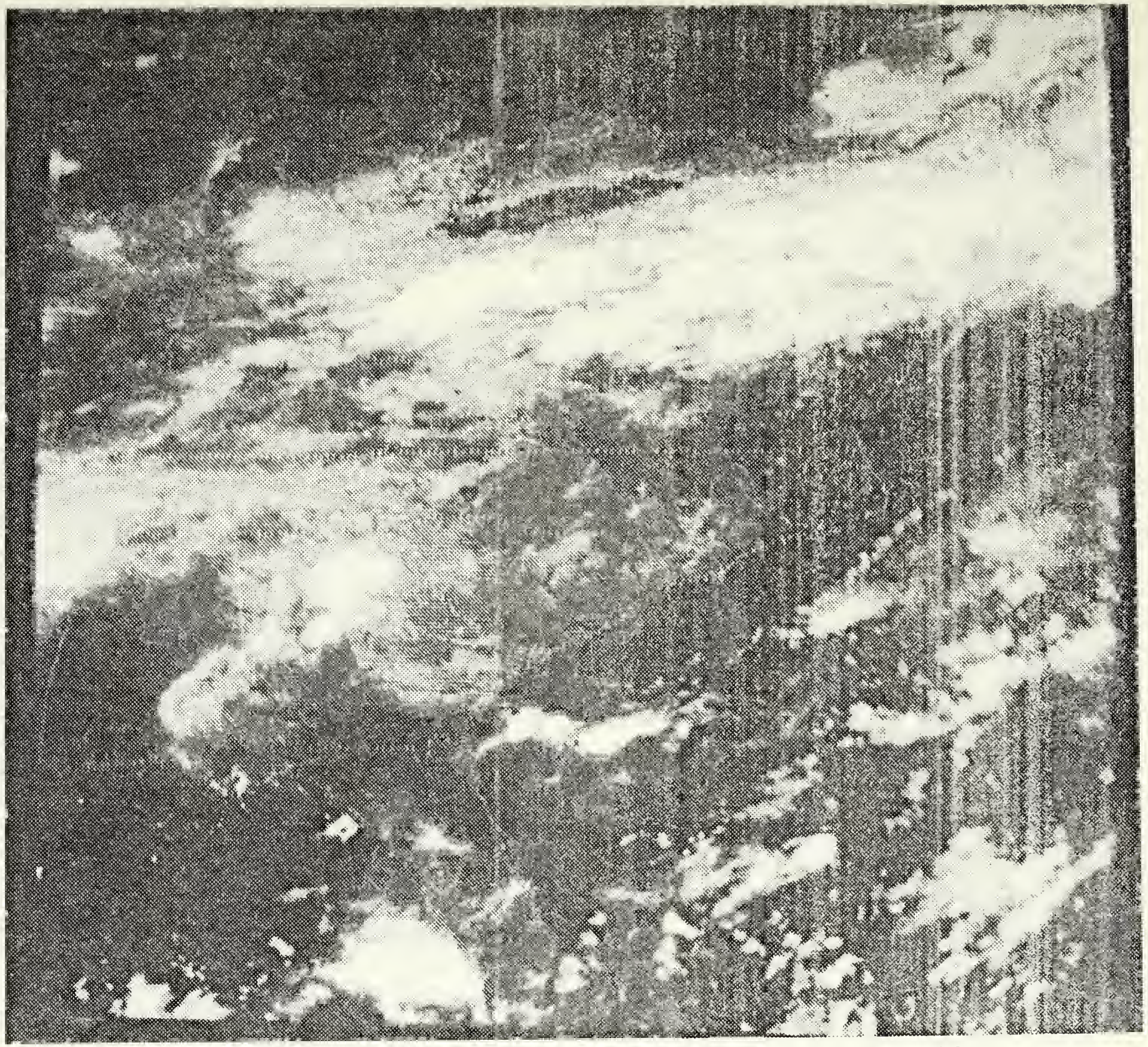

Figure 35. GOES Visual Imagery for 31 AUG 83

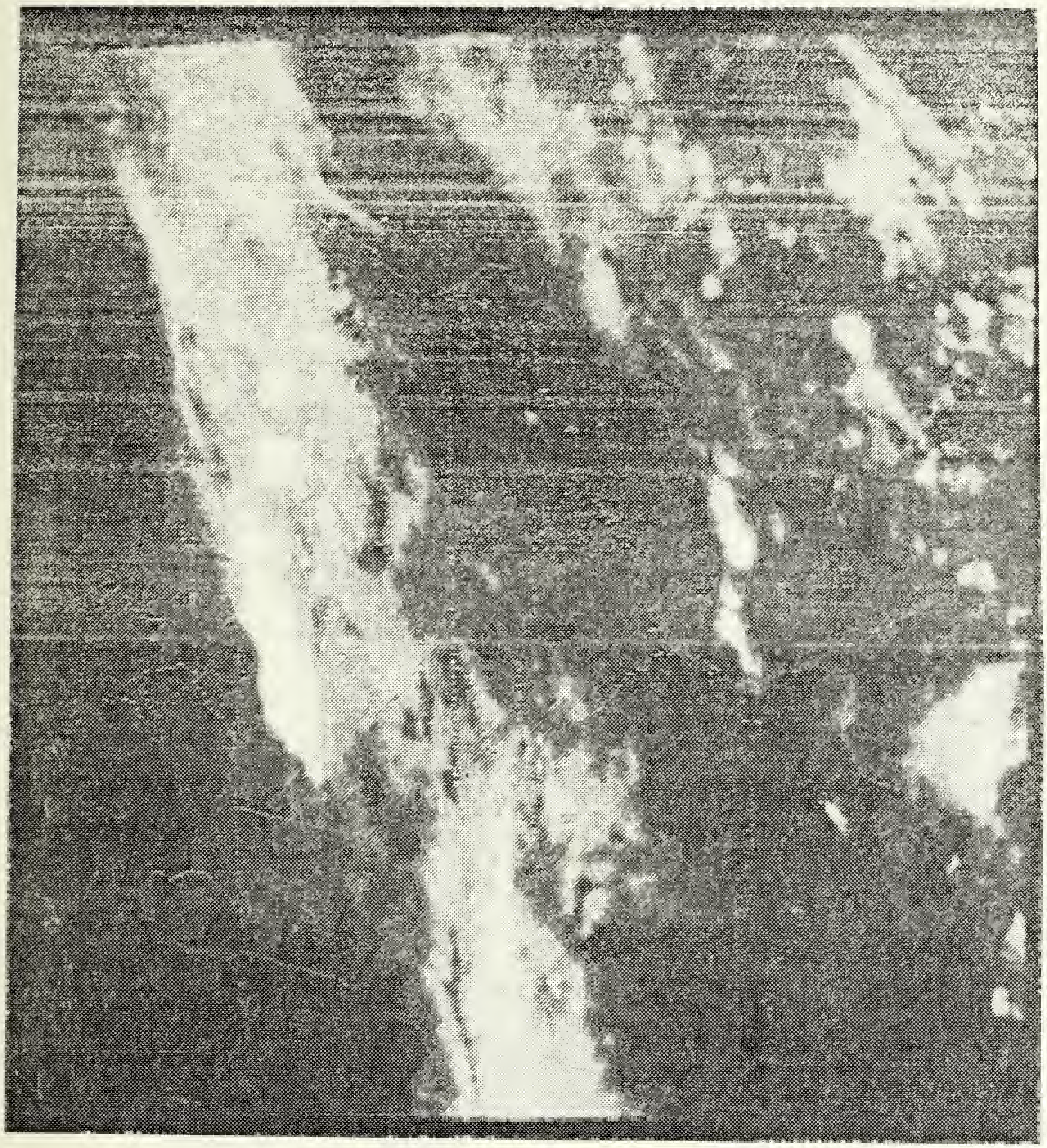

Figure 36. GOES Infrared Imagery for 31 AUG 83

Figure 37. Manual Satellite Analysis Verification Chart for 31 AUG 83

Figure 38. Surface Observation and ARS Verification Chart for 31 AUG 83

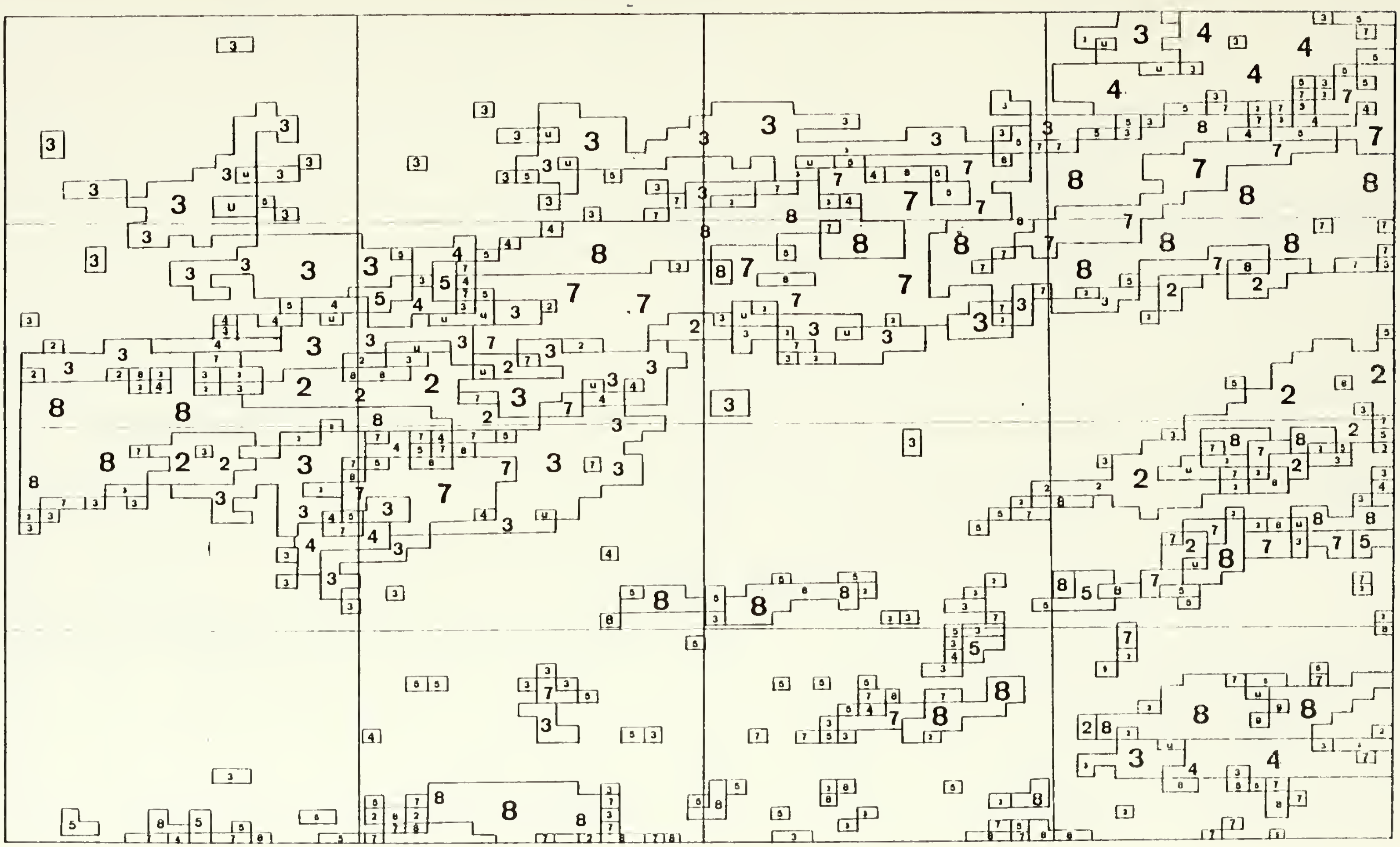

Figure 39. SPADS Contoured Cloud Type for 31 AUG 83

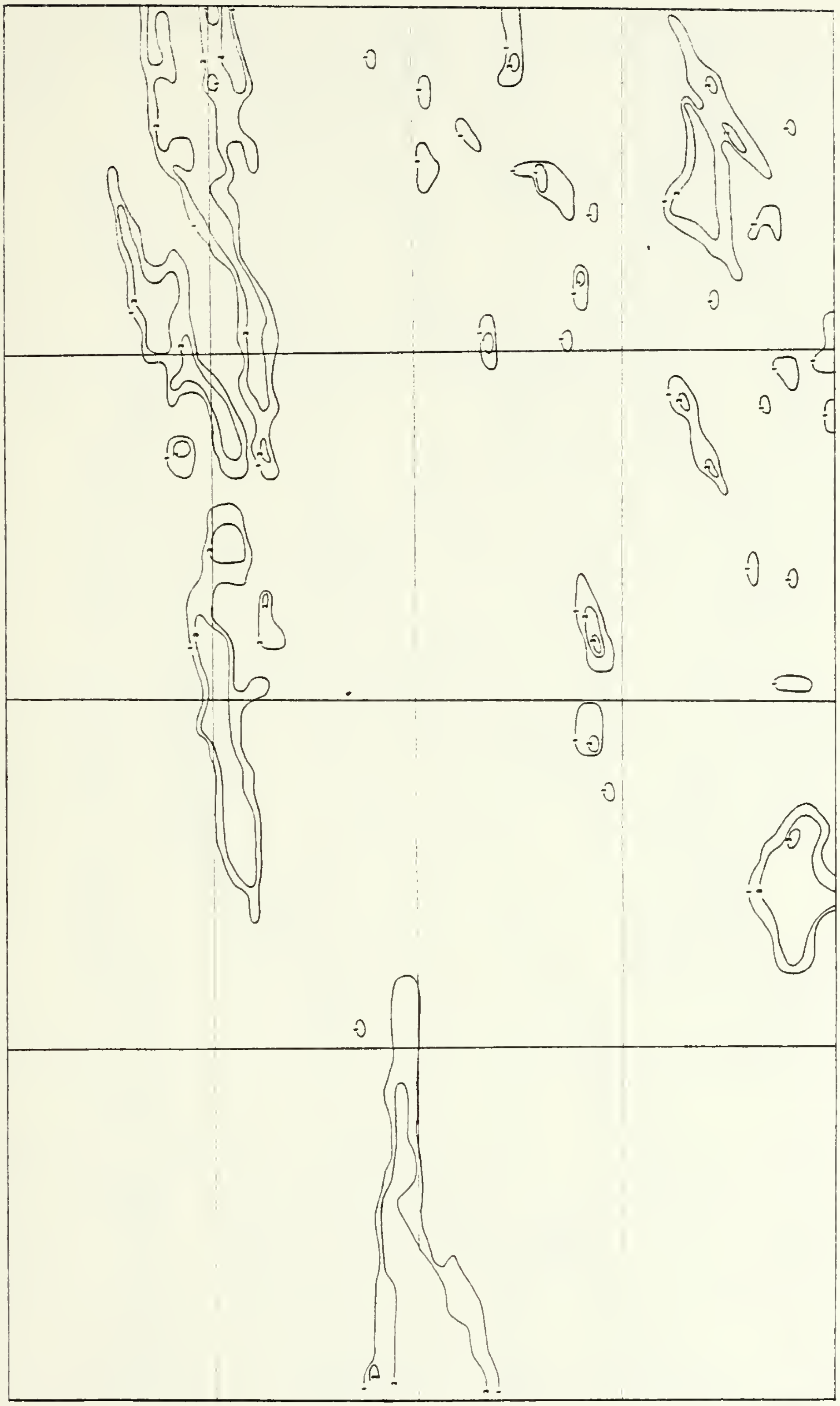

Figure 40. SPADS Contoured Precipitation Intensity for 31 AUG 83

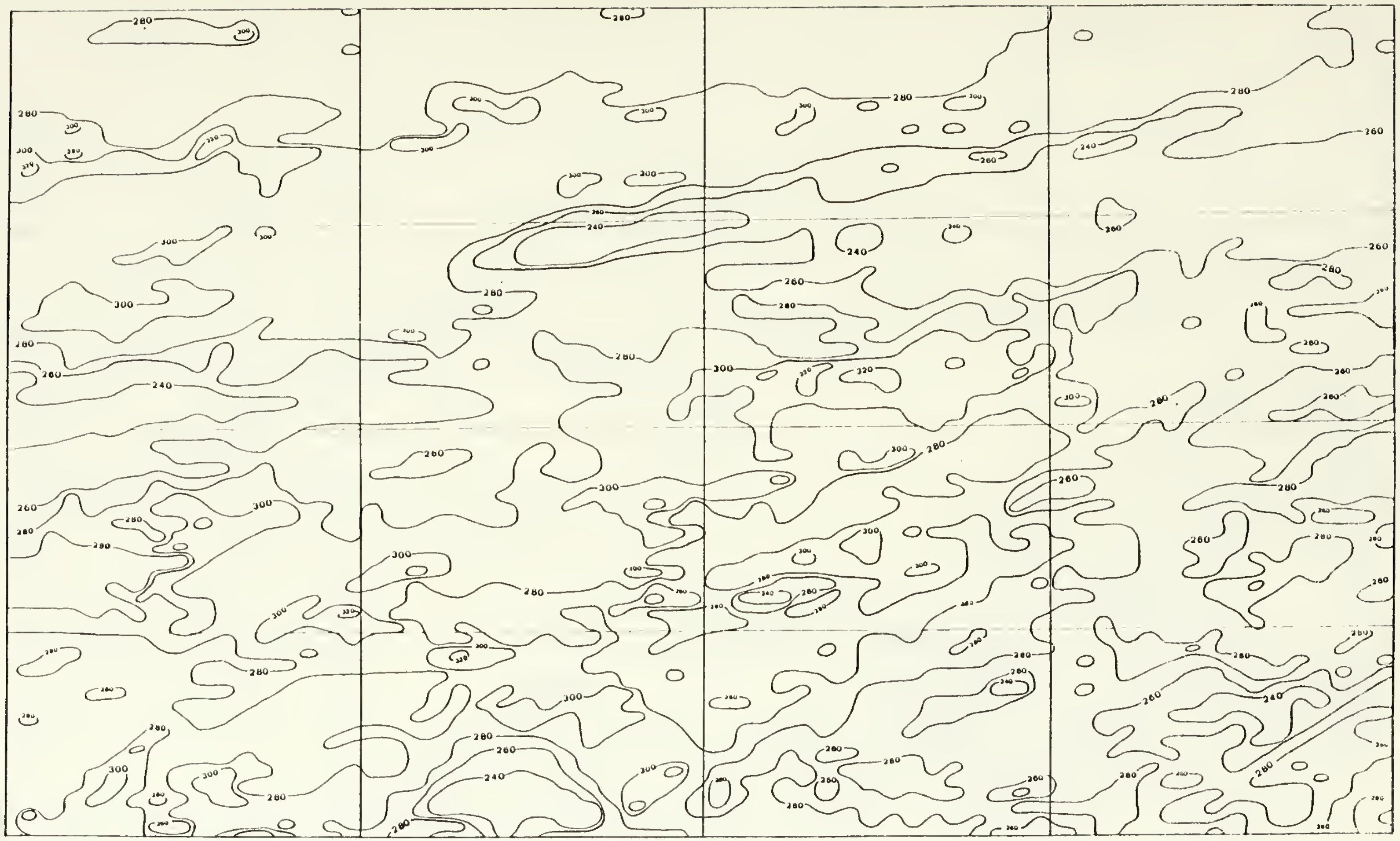

Figure 41. SPADS Contoured Cloud-Top Temperature for 31 AUG 83

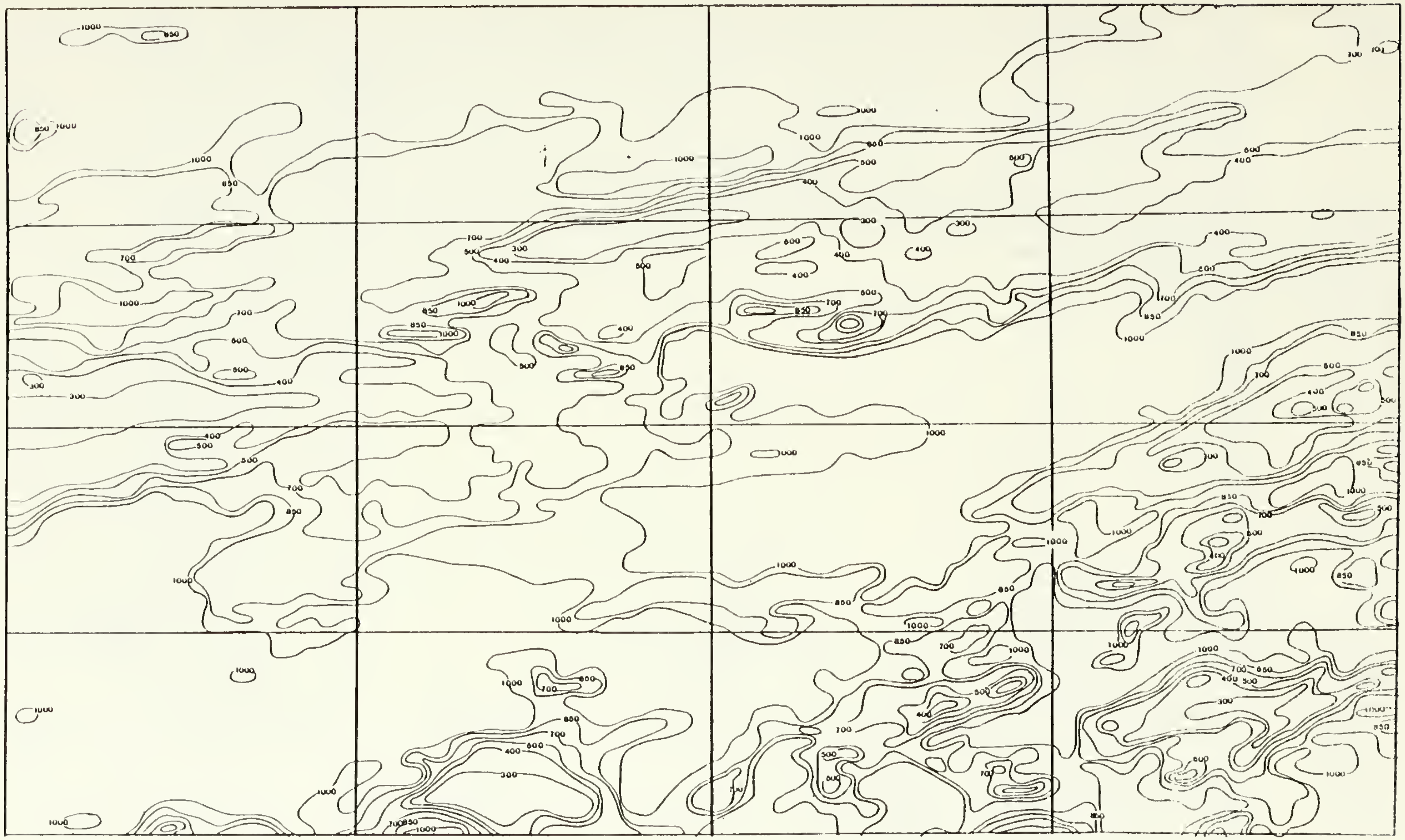

Figure 42. SPADS Contoured Cloud-Top Height for 31 AUG 83

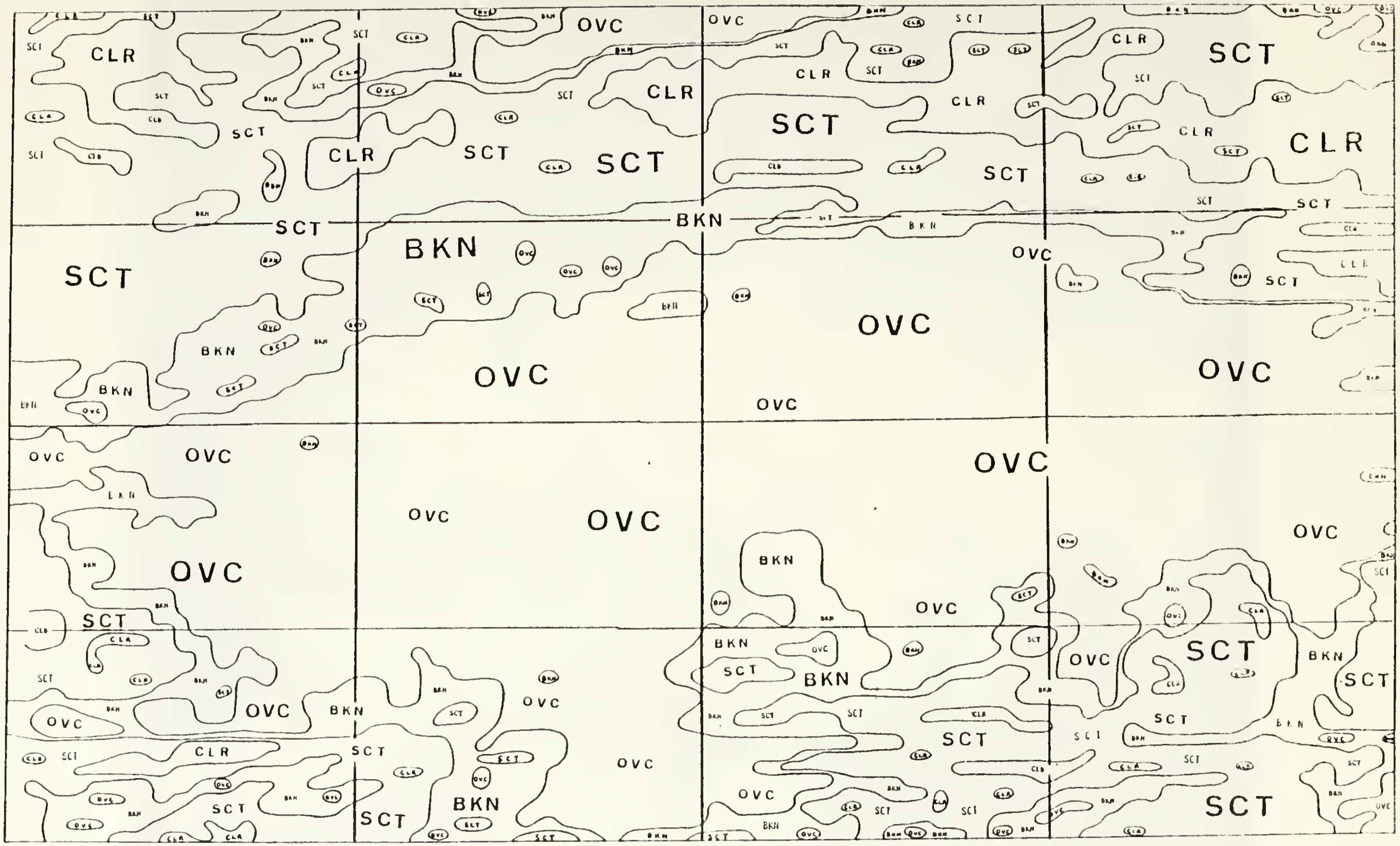

Figure 43. SPADS Contoured Cloud Amount for 02 SEP 83

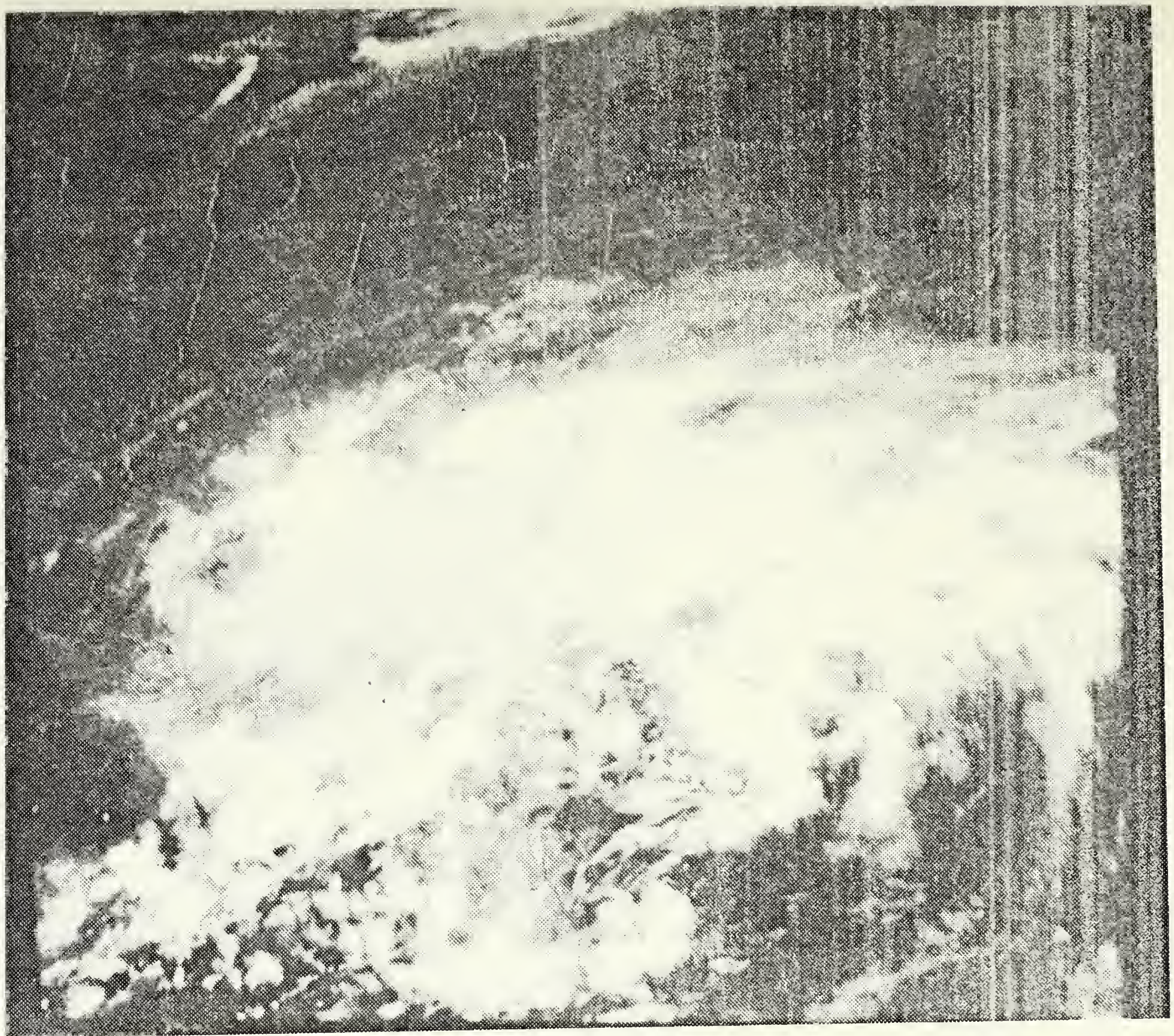

Figure 44. GOES Visual Imagery for 02 SEP 83

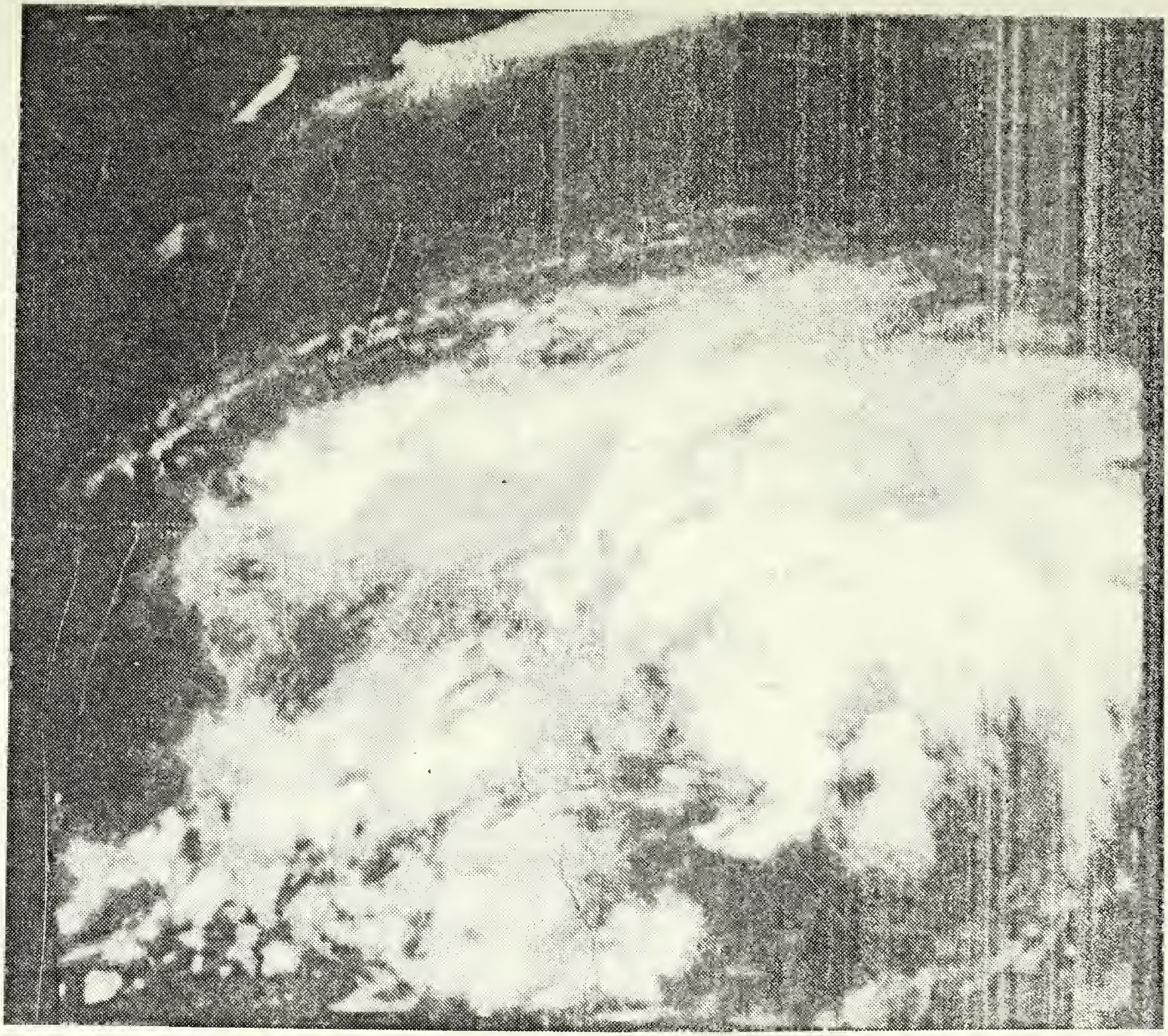

Figure 45. GOES Infrared Imagery for 02 SEP 83

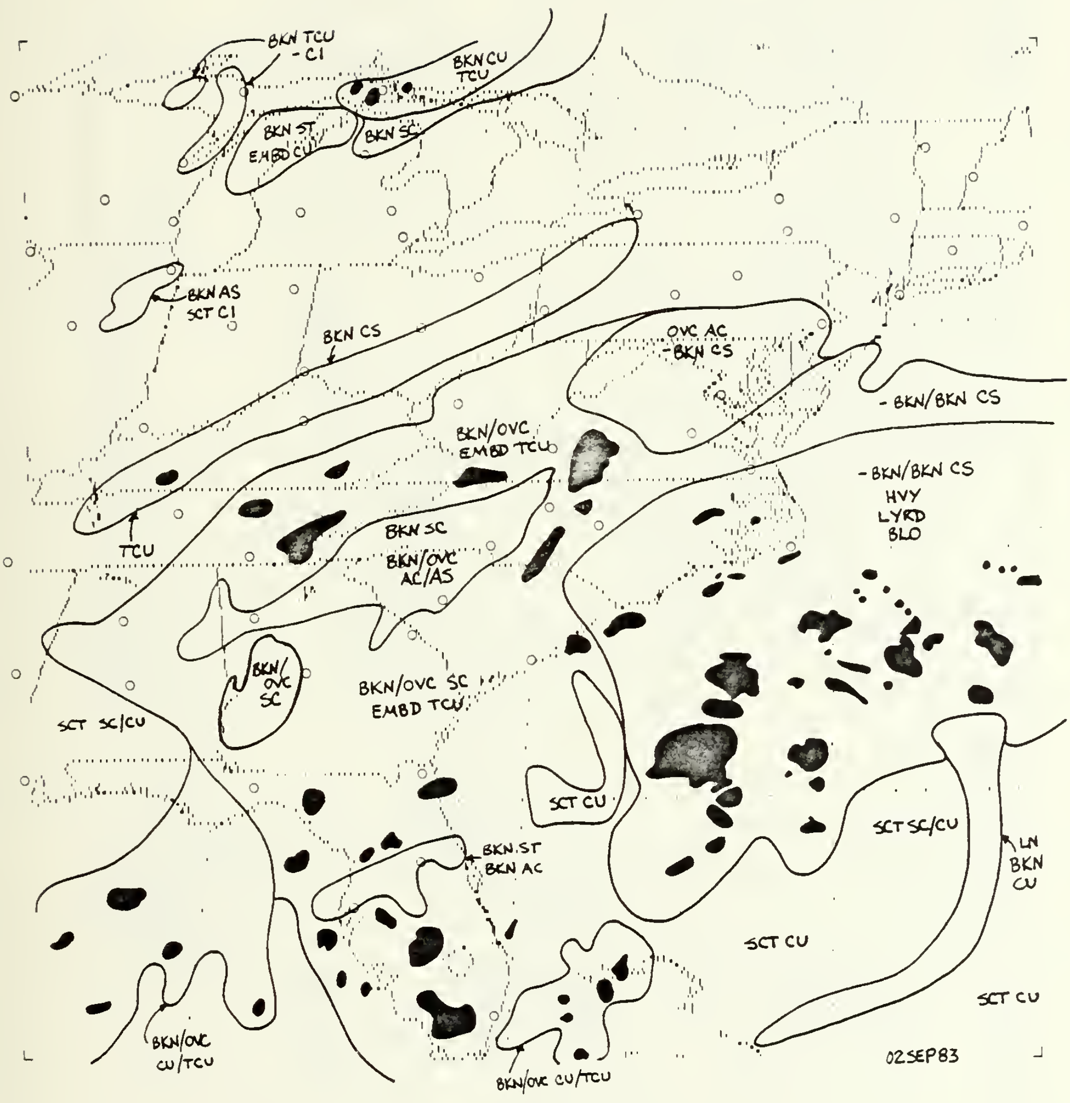

Figure 46. Manual Satellite Analysis Verification Chart for 02 SEP 83

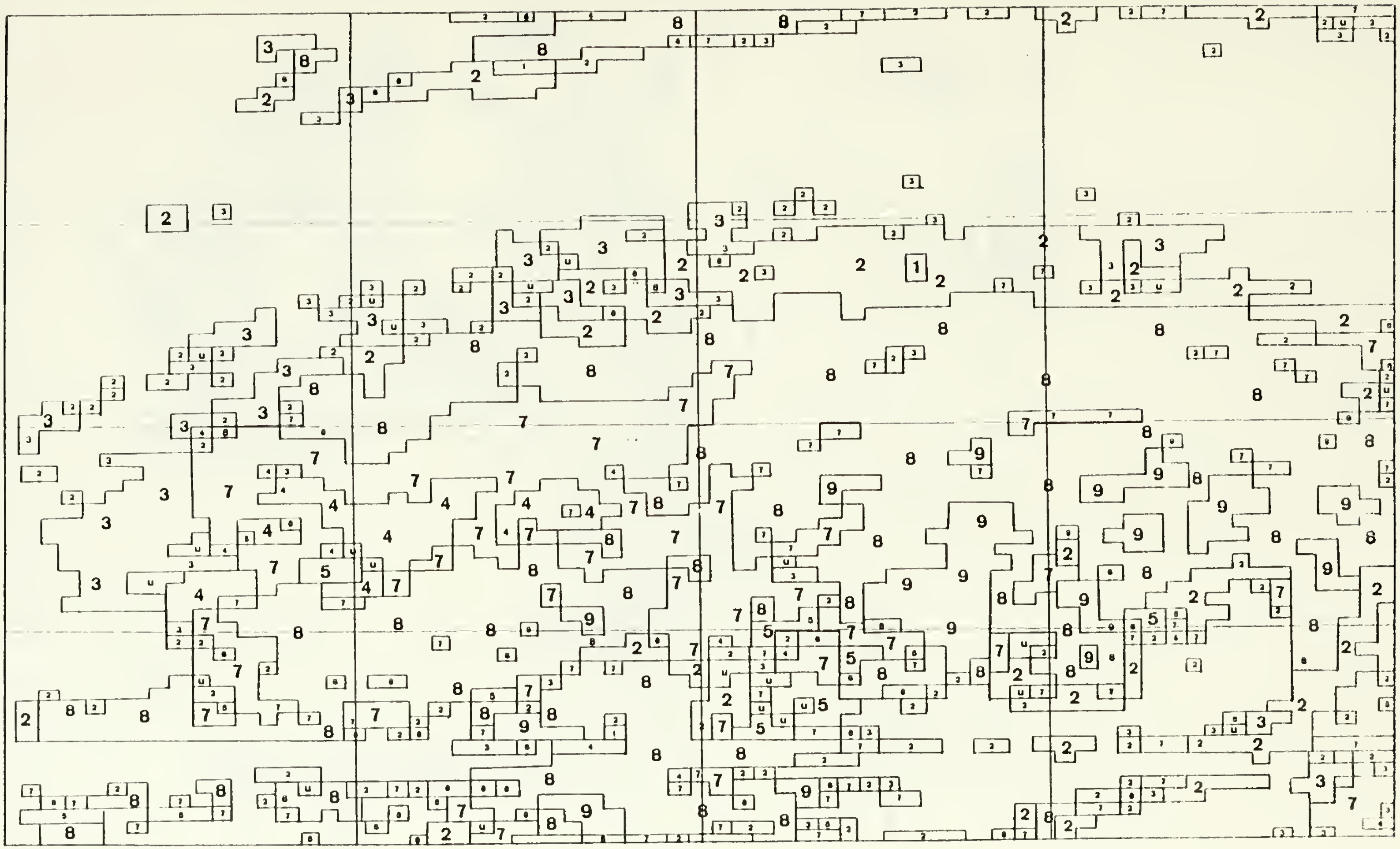

Figure 47. SPADS Contoured Cloud Type for 02 SEP 83

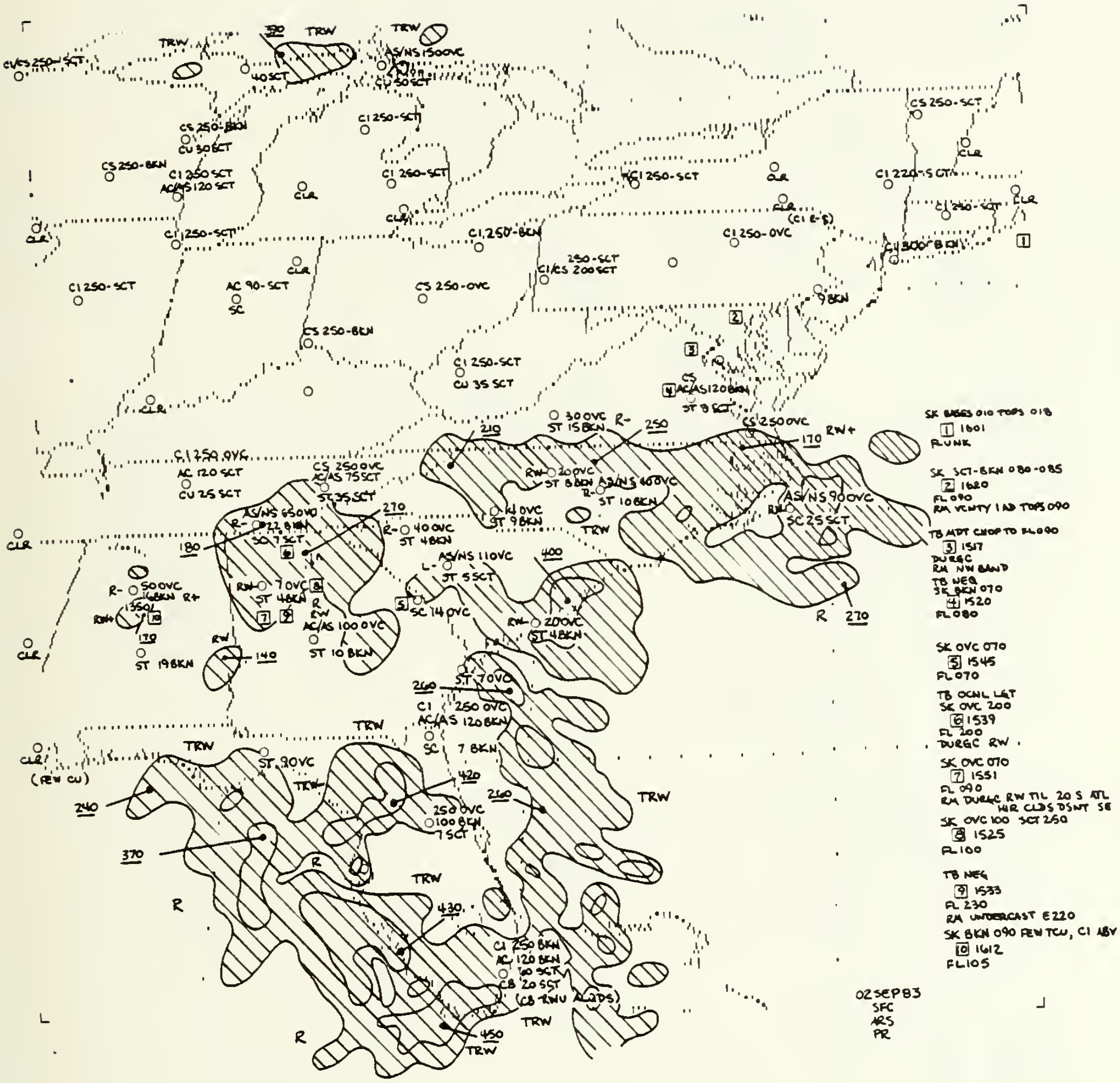

Figure 48. Surface Observation and ARS Verification Chart for 02 SEP 83

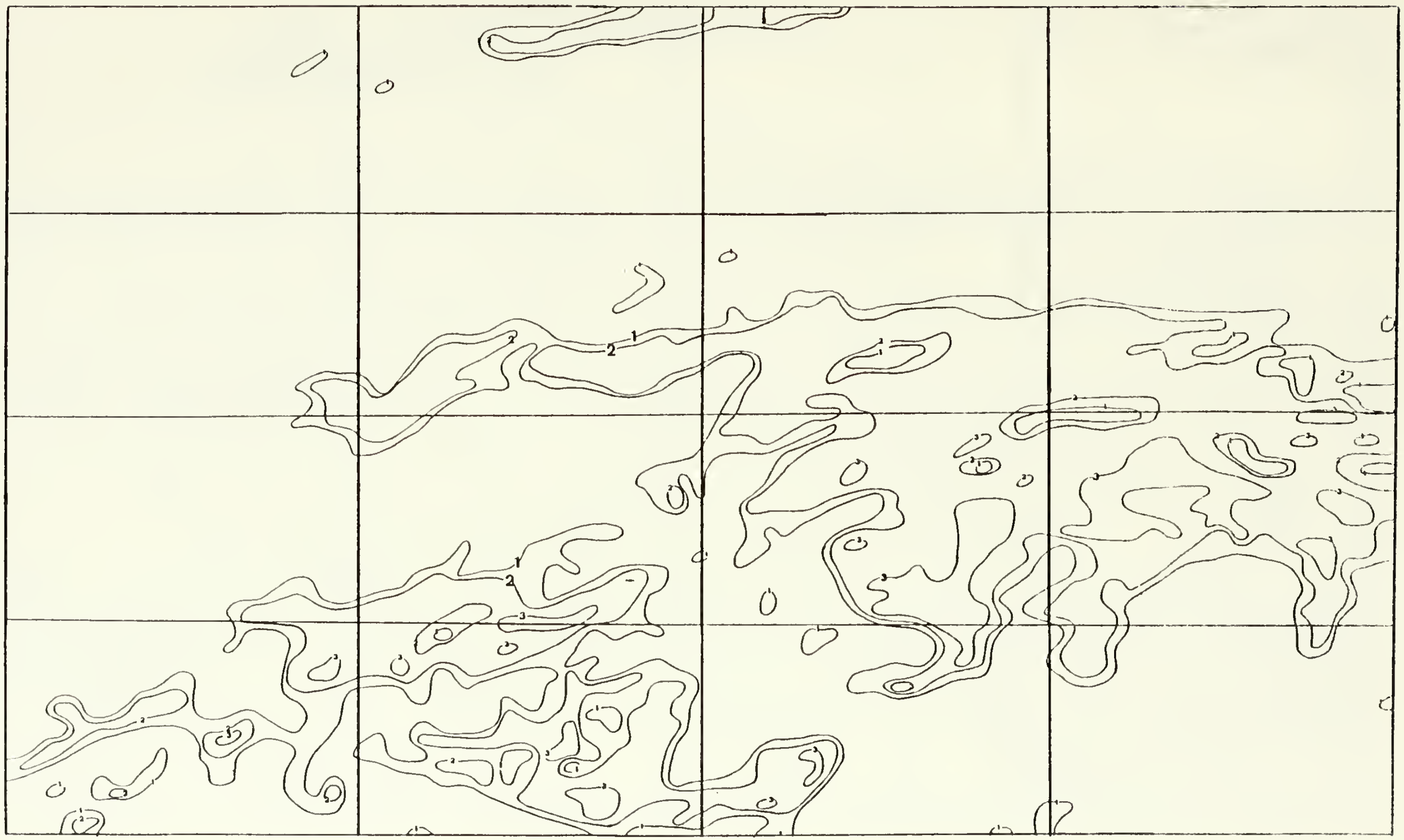

Figure 49. SPADS Contoured Precipitation Intensity for 02 SEP 83

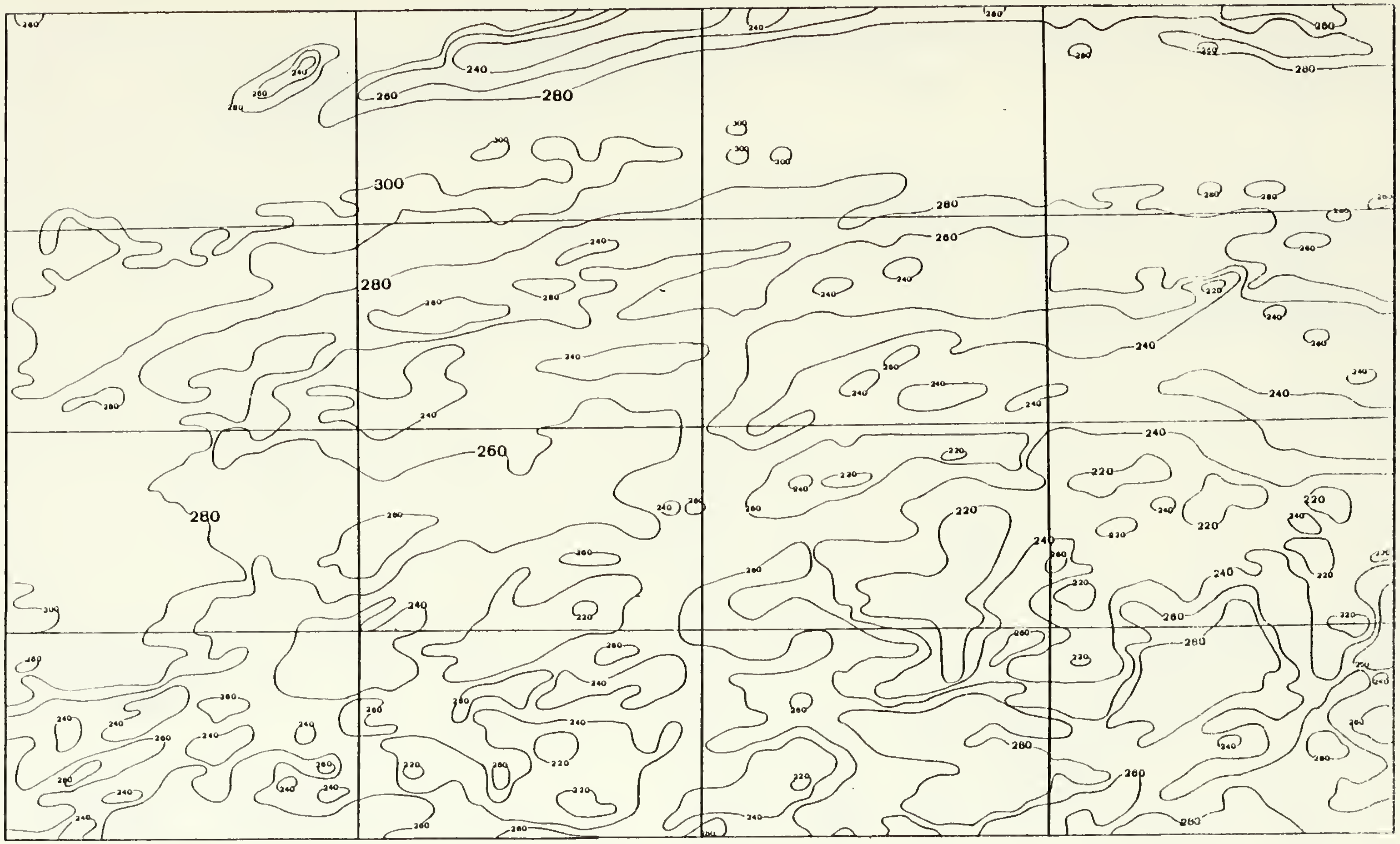

Figure 50. SPADS Contoured Cloud-Top Temperature for 02 SEP 83

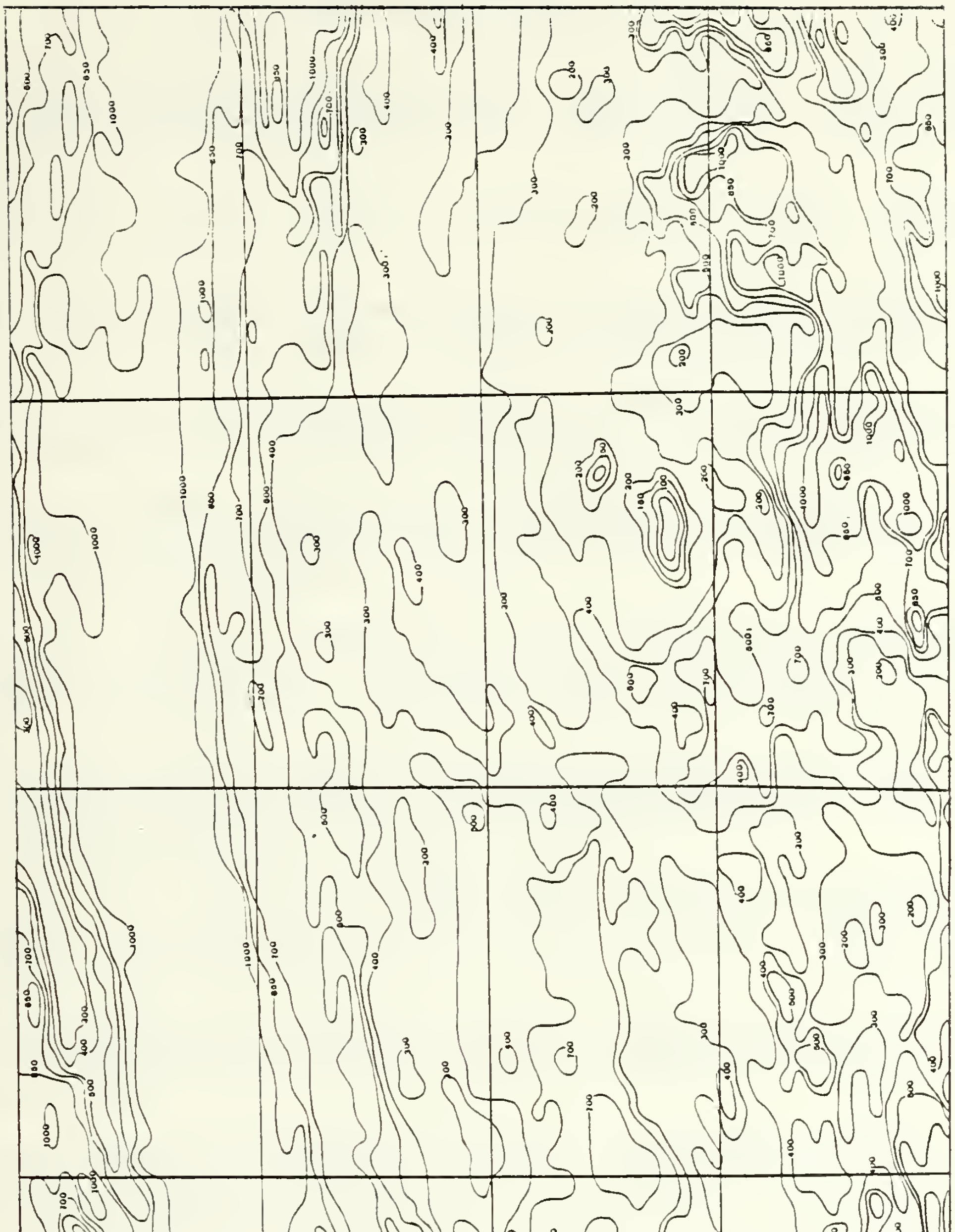

Figure 51. SPADS Contoured Cloud-Top Height for 02 SEP 83

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